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(54) **MICRO-ACTUATOR WITH INTEGRATED TRACE AND BONDING PAD SUPPORT**

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G11B 5/56 (2006.01)
G11B 21/20 (2006.01)

(52) **U.S. Cl.** **360/294.4**

(58) **Field of Classification Search** 360/294.4
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,299,081	A	3/1994	Hatch et al.	
5,611,707	A	3/1997	Meynier	
5,636,089	A	6/1997	Jurgenson et al.	
5,898,544	A	4/1999	Krinke et al.	
6,198,606	B1	3/2001	Boutaghou et al.	
6,538,836	B1	3/2003	Dunfield et al.	
6,617,763	B2	9/2003	Mita et al.	
6,624,984	B2	9/2003	Lewis et al.	
6,671,131	B2	12/2003	Kasajima et al.	
6,700,727	B1	3/2004	Crane et al.	
6,700,749	B2	3/2004	Shiraishi et al.	
6,930,860	B1 *	8/2005	Coffey	360/294.4
6,934,127	B2 *	8/2005	Yao et al.	360/294.4
6,950,266	B1	9/2005	McCaslin et al.	
6,950,288	B2 *	9/2005	Yao et al.	360/294.4
7,051,424	B2 *	5/2006	Yao et al.	29/603.06
7,159,300	B2 *	1/2007	Yao et al.	29/603.03
2002/0051326	A1 *	5/2002	Shiraishi et al.	360/294.4
2002/0141117	A1 *	10/2002	Kasajima et al.	360/294.4
2002/0154450	A1 *	10/2002	Kasajima et al.	360/294.4
2003/0147177	A1	8/2003	Yao et al.	
2003/0147181	A1	8/2003	Shiraishi et al.	
2003/0168935	A1	9/2003	Ogawa et al.	
2003/0231434	A1 *	12/2003	Mita et al.	360/294.4
2004/0037008	A1 *	2/2004	Yao et al.	360/294.3

(Continued)

FOREIGN PATENT DOCUMENTS

JP	2002-74871	3/2002

(Continued)

OTHER PUBLICATIONS

U.S. Appl. No. 11/238,998, filed Sep. 2005, Yang et al.

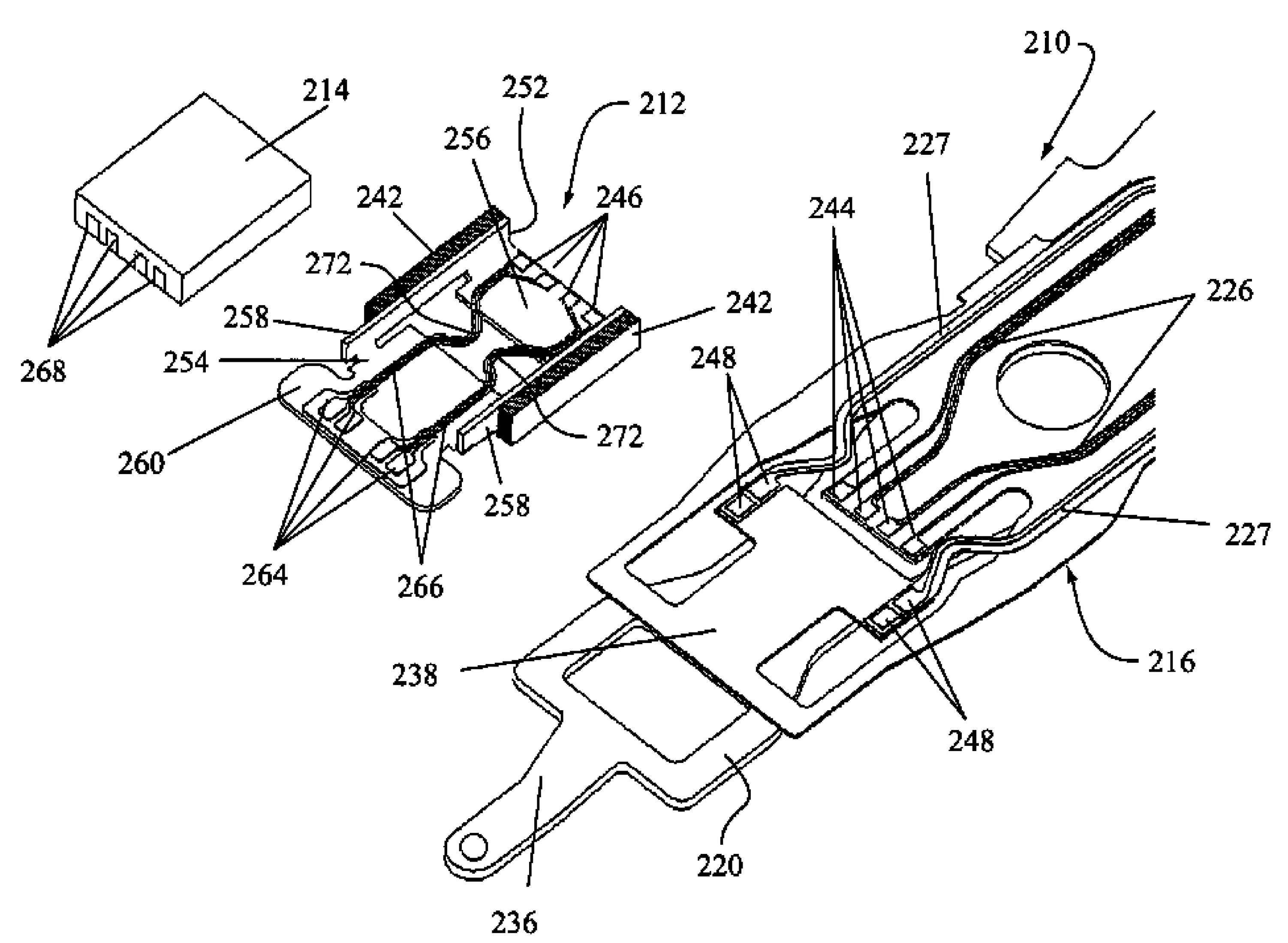
(Continued)

Primary Examiner—William J Klimowicz
(74) *Attorney, Agent, or Firm*—Nixon & Vanderhye P.C.

(57) **ABSTRACT**

A micro-actuator for a head gimbal assembly includes a frame, a first set of bonding pads provided to one end of the frame, a second set of bonding pads provided to an opposing end of the frame, and a trace integrated to the frame. The trace interconnects the first set of bonding pads and the second set of bonding pads.

37 Claims, 19 Drawing Sheets



U.S. PATENT DOCUMENTS

2004/0070887	A1 *	4/2004	Yao et al.	360/294.4
2004/0095684	A1 *	5/2004	Yao et al.	360/294.3
2004/0145834	A1 *	7/2004	Miyano et al.	360/294.4
2005/0152072	A1 *	7/2005	Kwon et al.	360/294.4
2005/0195531	A1 *	9/2005	Yamazaki et al.	360/294.4
2006/0023338	A1	2/2006	Sharma et al.	
2006/0050442	A1	3/2006	Yao et al.	
2006/0072247	A1	4/2006	Yao et al.	
2006/0082917	A1	4/2006	Yao et al.	
2006/0098347	A1	5/2006	Yao et al.	
2006/0146449	A1	7/2006	Yao et al.	

FOREIGN PATENT DOCUMENTS

JP	2002-133803	5/2002

OTHER PUBLICATIONS

U.S. Appl. No. 11/169,019, filed Jun. 2005, Yao et al.
U.S. Appl. No. 11/080,659, filed Mar. 2005, Yao et al.
U.S. Appl. No. 11/050,823, filed Jan. 2005, Yao et al.
U.S. Appl. No. 11/080,657, filed Mar. 2005, Zhu et al.
U.S. Appl. No. 11/235,549, filed Sep. 2005, Yao et al.
U.S. Appl. No. 11/304/623, filed Dec. 2005, Yao et al.
U.S. Appl. No. 11/125,248, filed May 2005, Yao et al.
U.S. Appl. No. 11/263,998, filed Nov. 2005, Yao.
U.S. Appl. No. 11/265,385, filed Nov. 2005, Yao et al.
U.S. Appl. No. 11/192,121, filed Jul. 2005, Yao et al.
U.S. Appl. No. 11/304,544, filed Dec. 2005, Yao.
U.S. Appl. No. 11/300,339, filed Dec. 2005, Yao et al.
U.S. Appl. No. 11/385,704, filed Mar. 2006, Yao et al.
U.S. Appl. No. 11/385,698, filed Mar. 2006, Yao et al.
U.S. Appl. No. 11/319,577, filed Dec. 2005, Yao et al.
U.S. Appl. No. 11/353,018, filed Feb. 2006, Yao.
U.S. Appl. No. 11/273,075, filed Nov. 2005, Yao.
U.S. Appl. No. 11/319,580, filed Dec. 2005, Yao et al.
U.S. Appl. No. 11/384,404, filed Mar. 2006, Yao.
U.S. Appl. No. 11/414,546, filed May 2006, Yao et al.
U.S. Appl. No. 11/440,354, filed May 2006, Li.

* cited by examiner

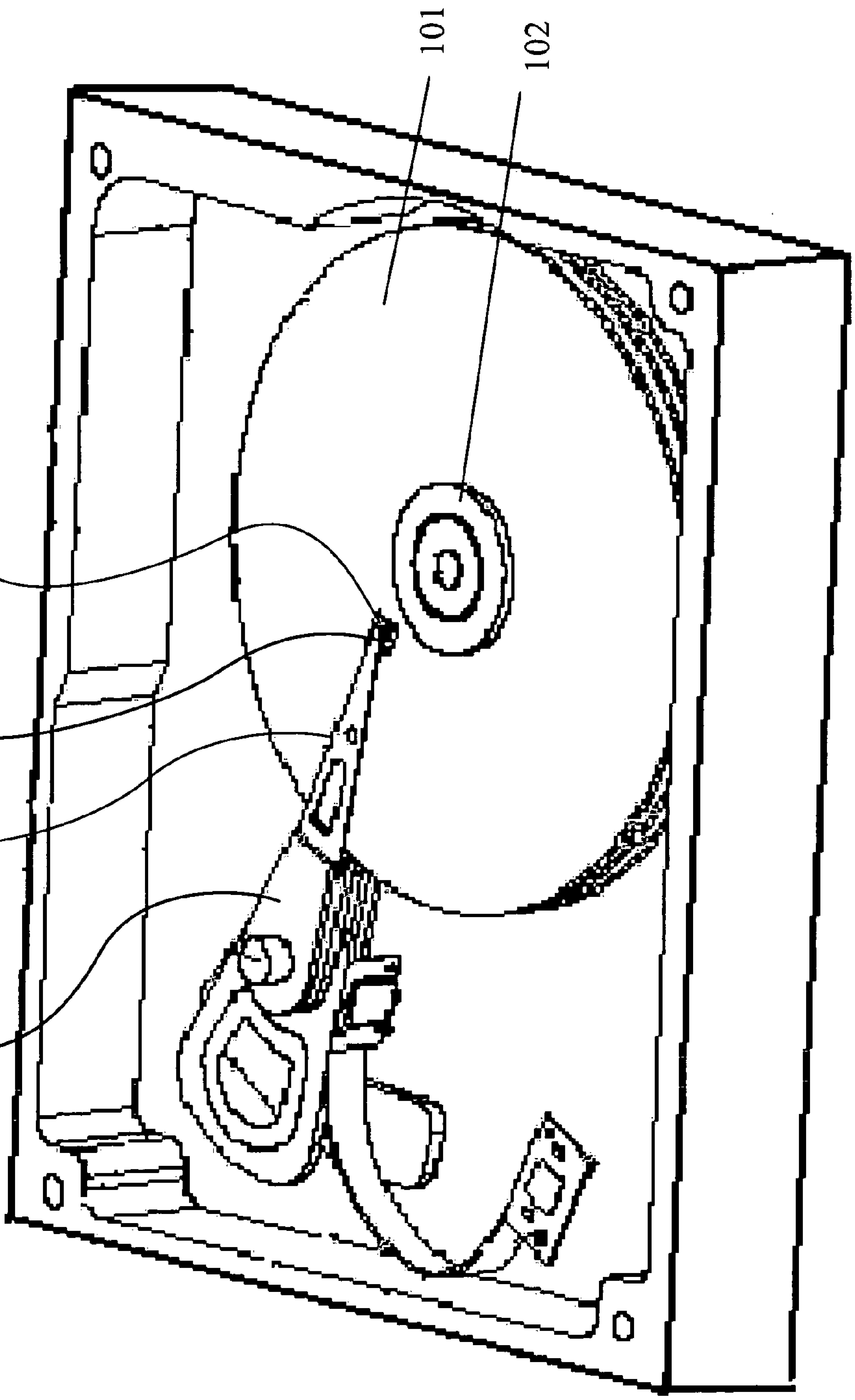


Fig. 1
(PRIOR ART)

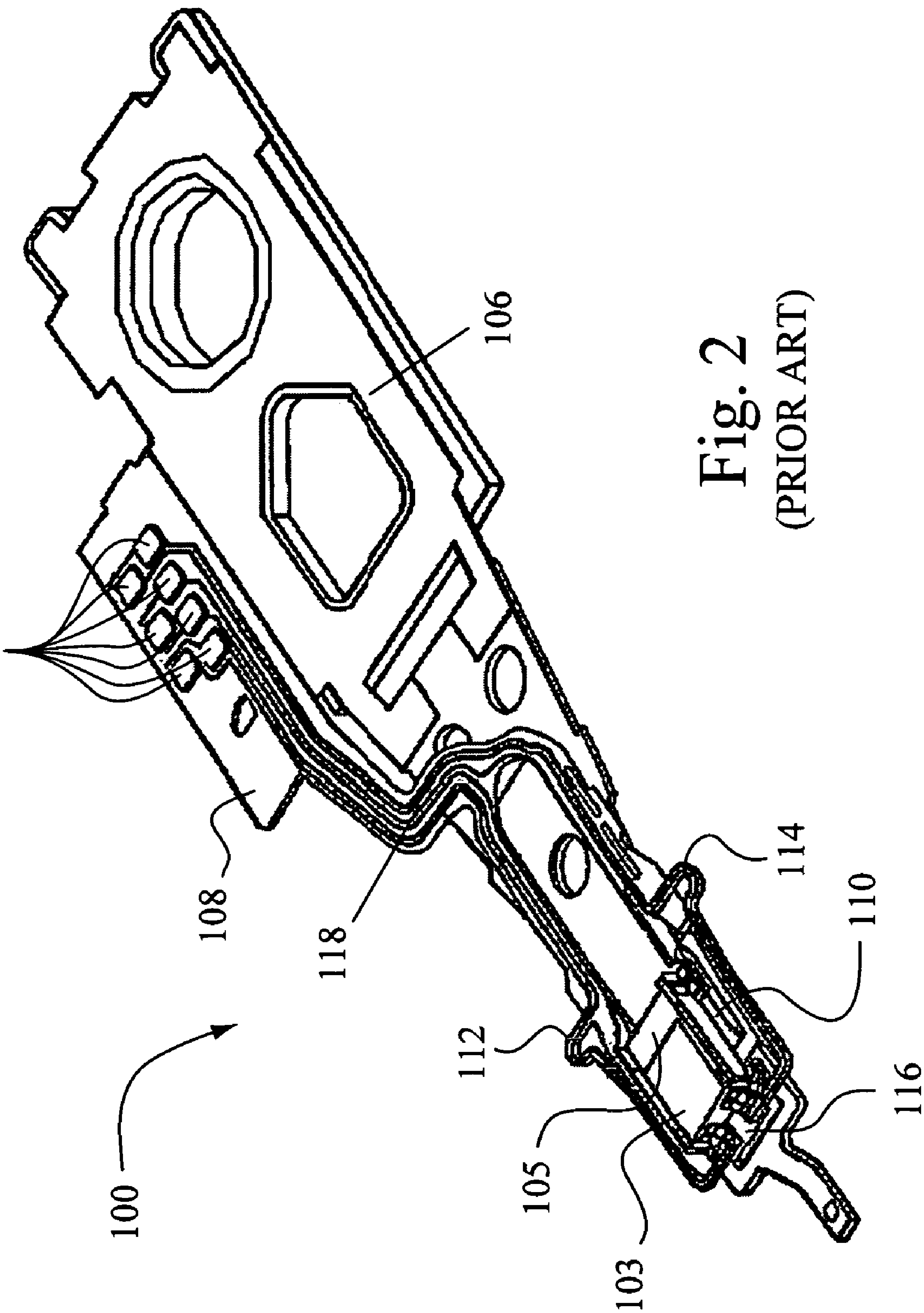


Fig. 2
(PRIOR ART)

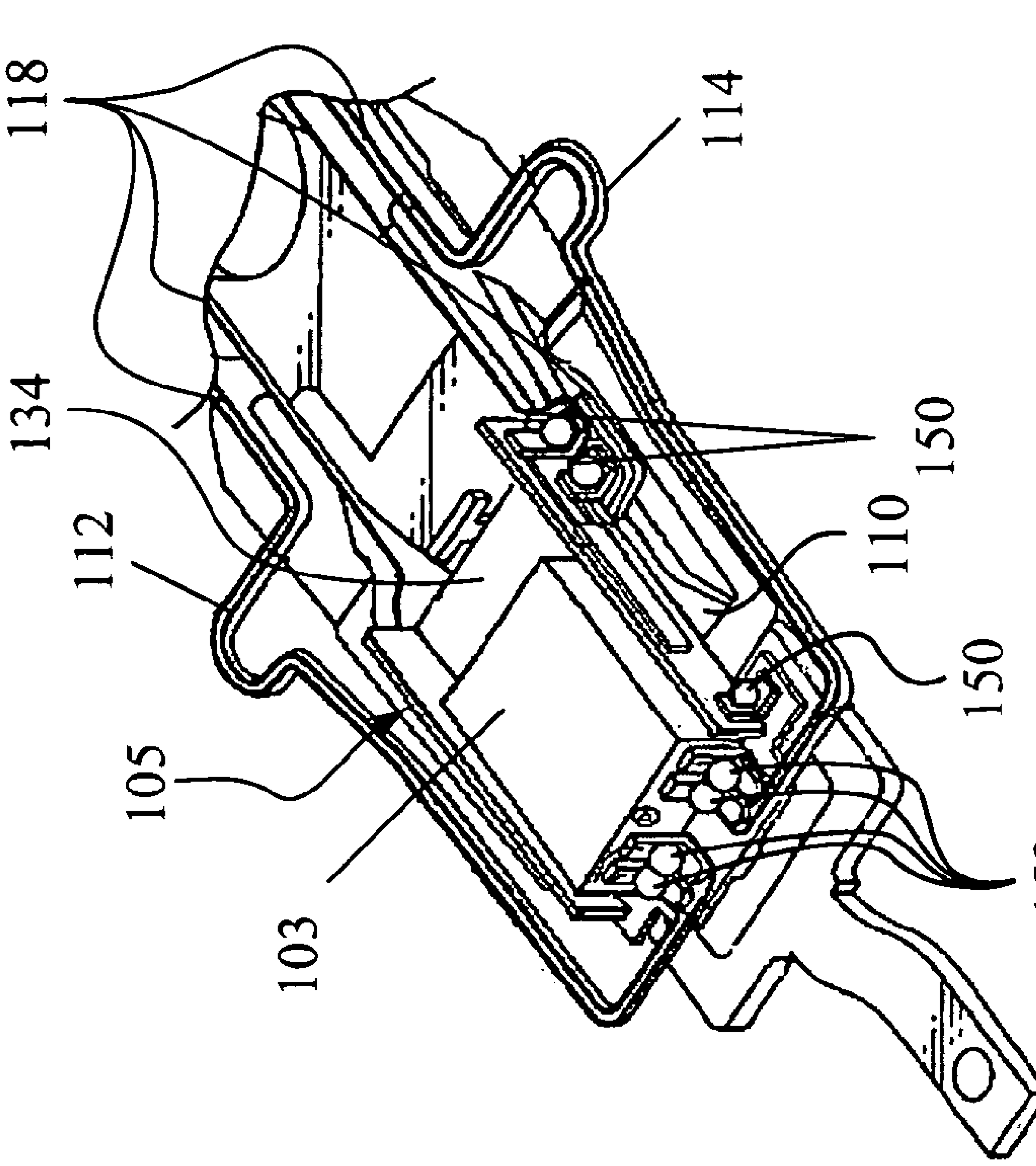


Fig. 4
(PRIOR ART)

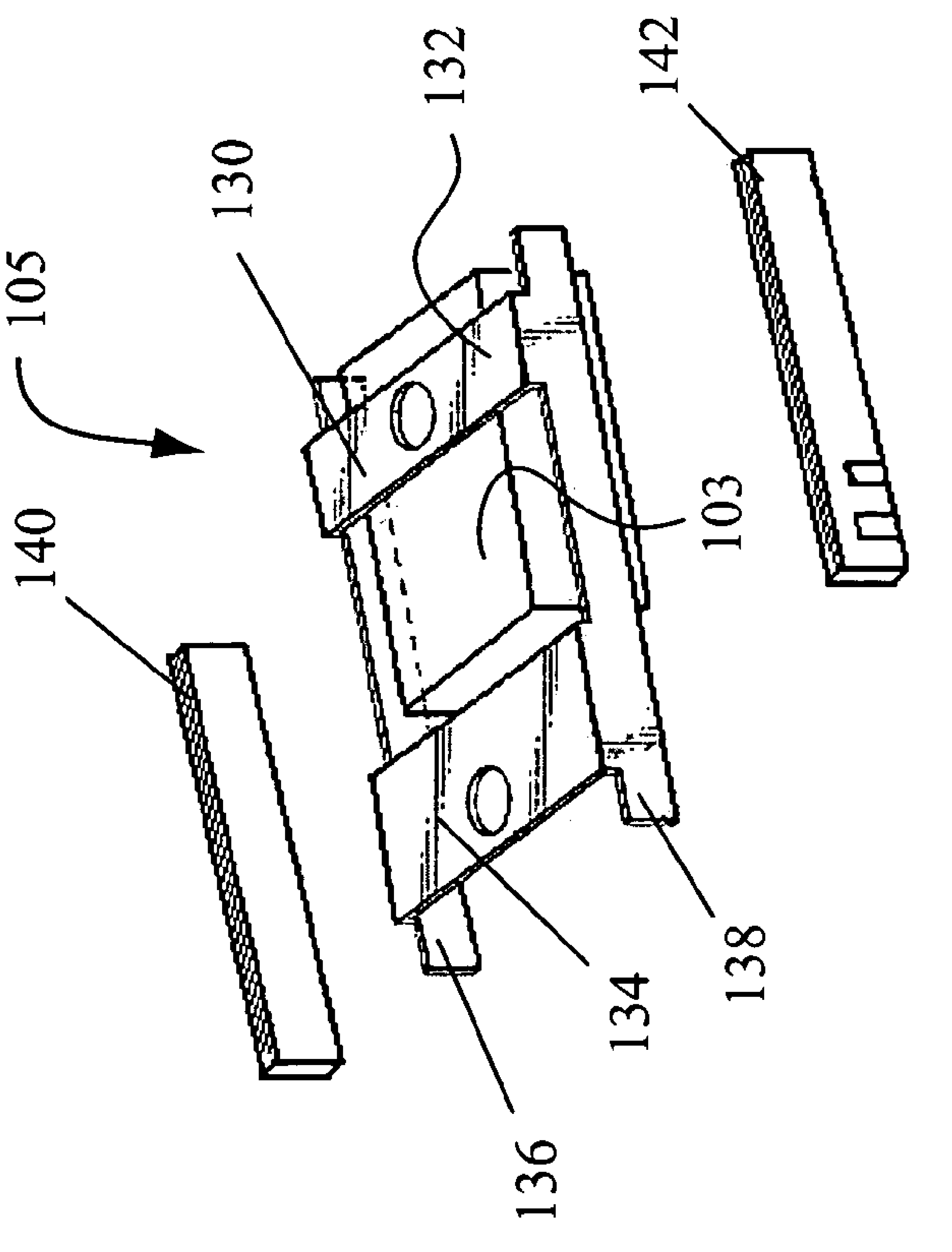


Fig. 3
(PRIOR ART)

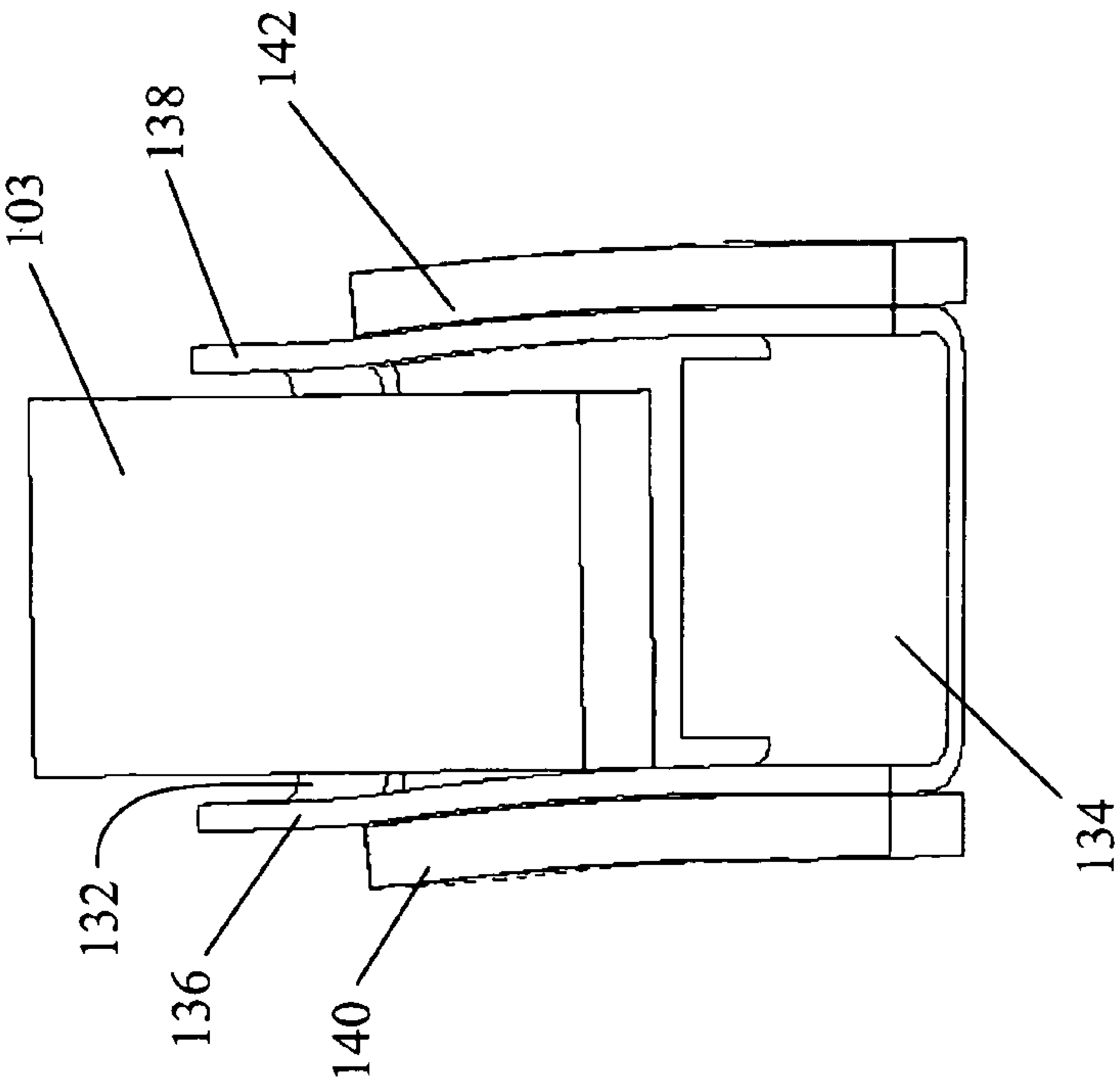


Fig. 5
(PRIOR ART)

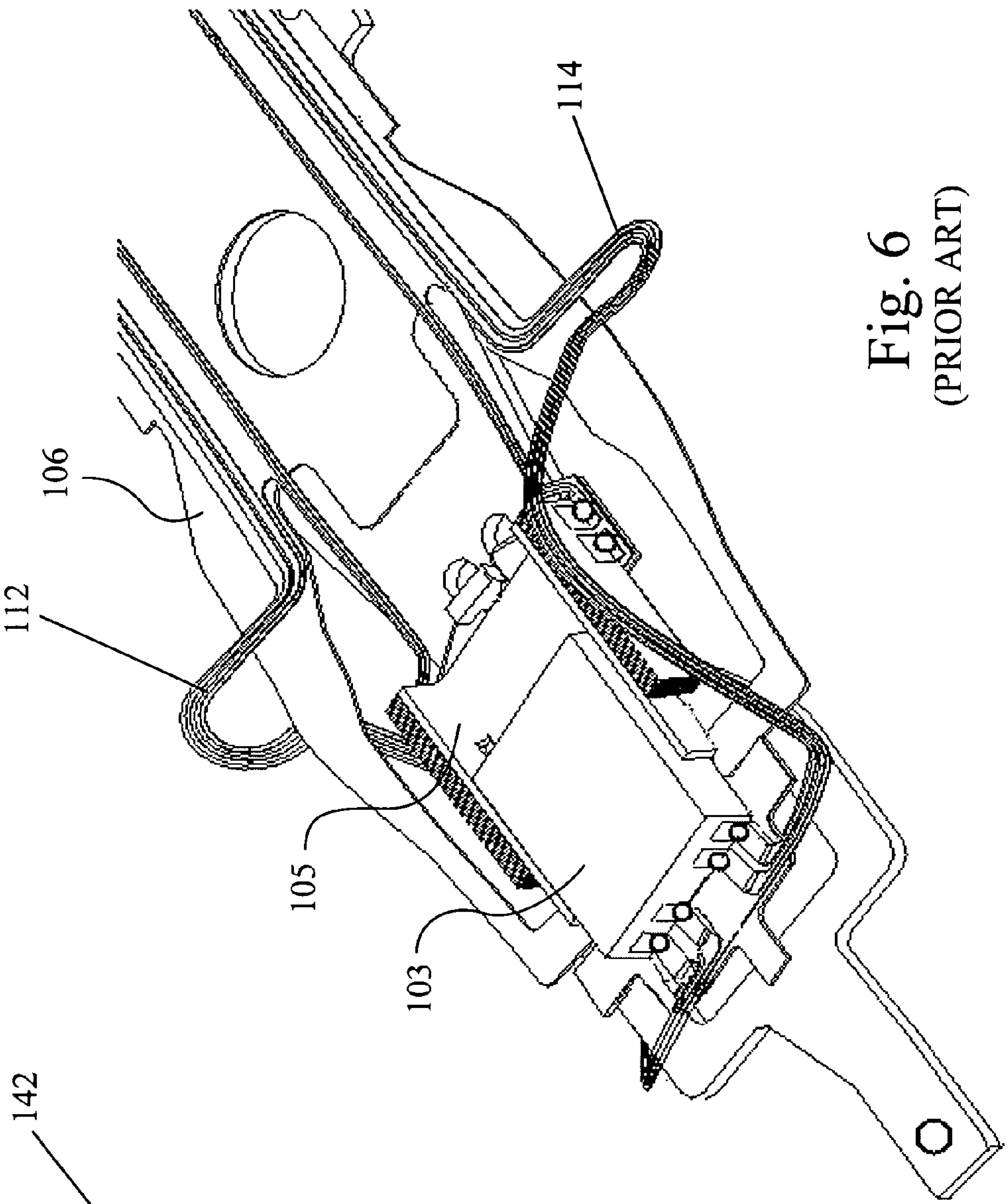


Fig. 6
(PRIOR ART)

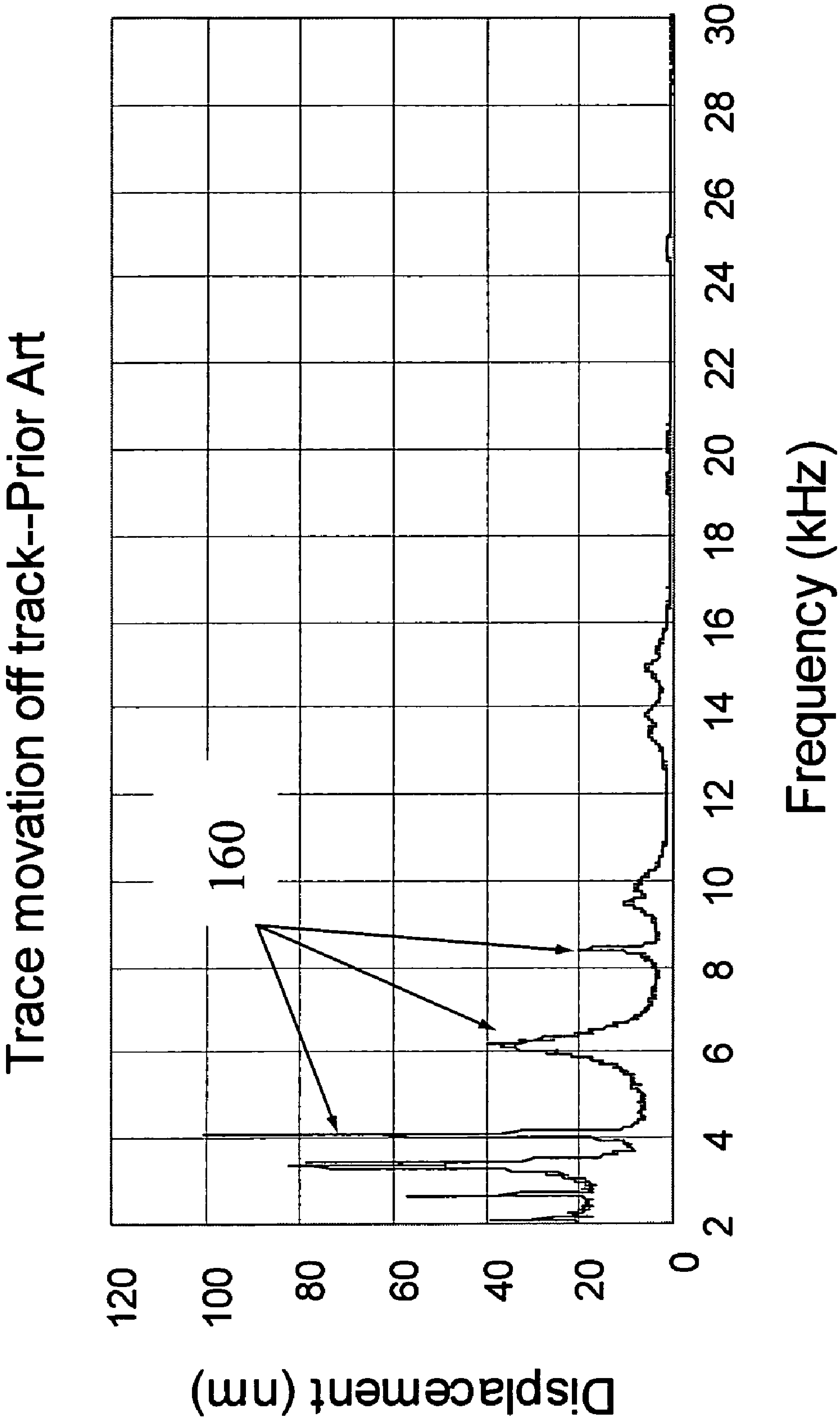


Fig. 7
(PRIOR ART)

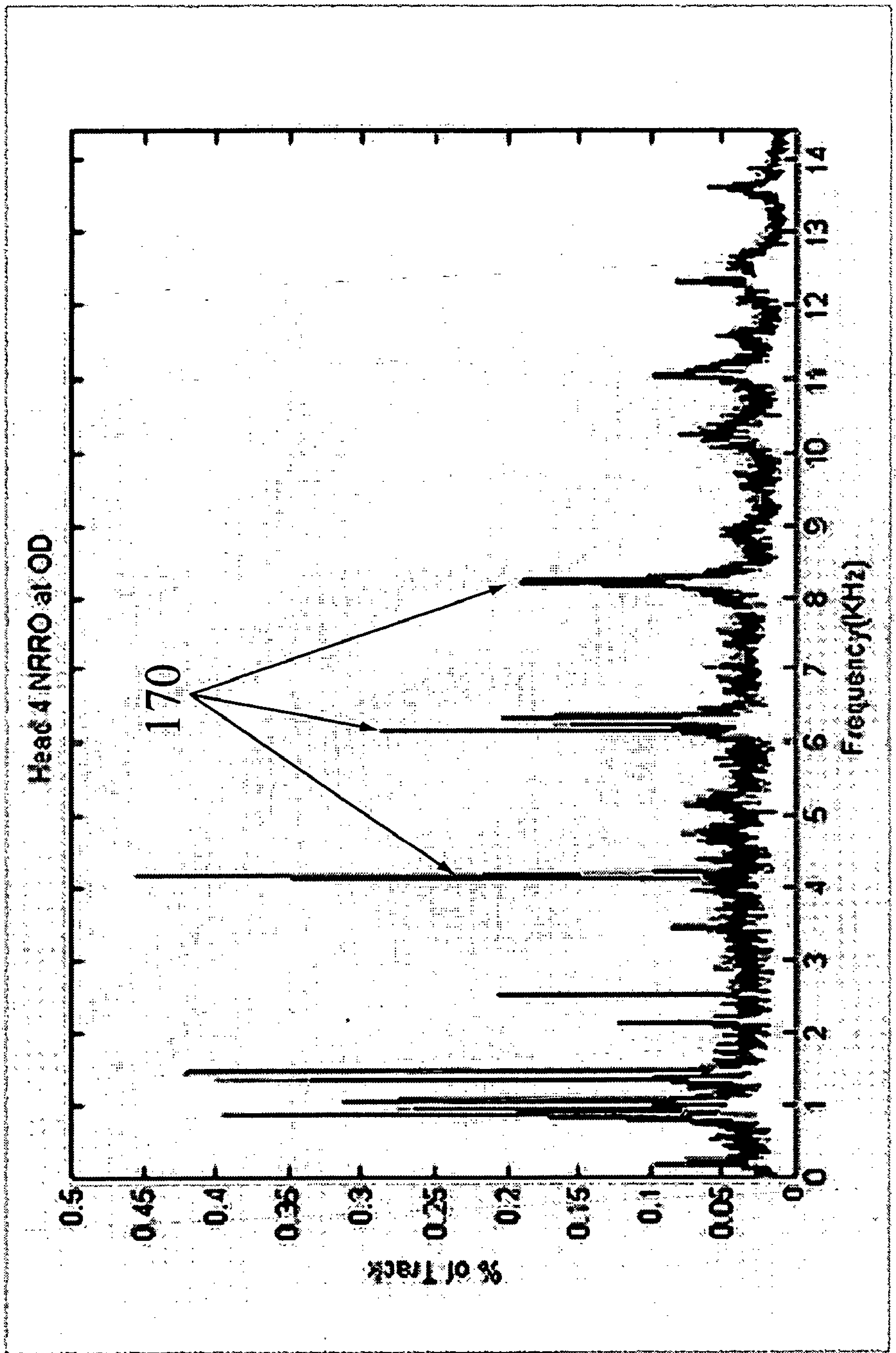


Fig. 8
(PRIOR ART)

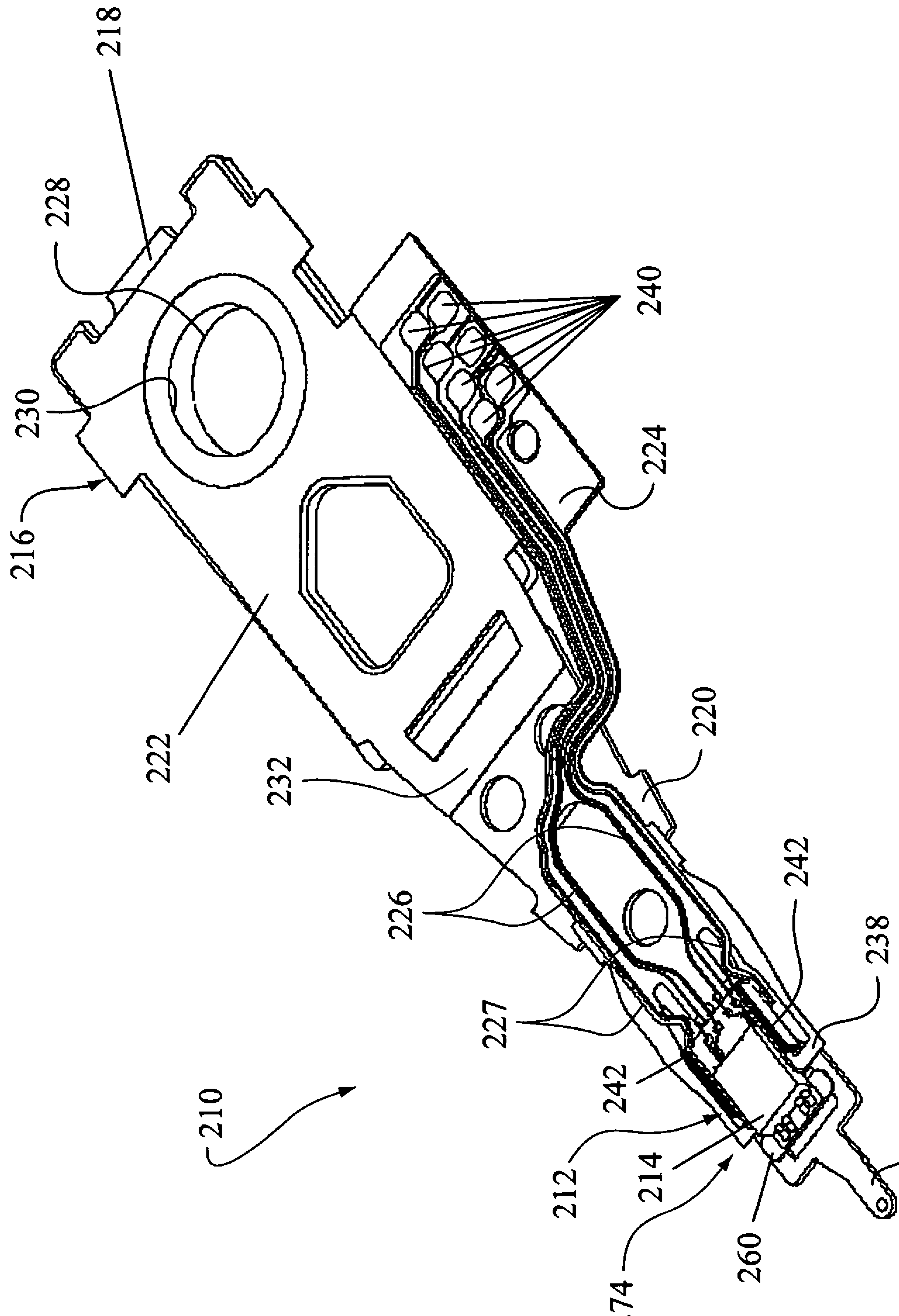
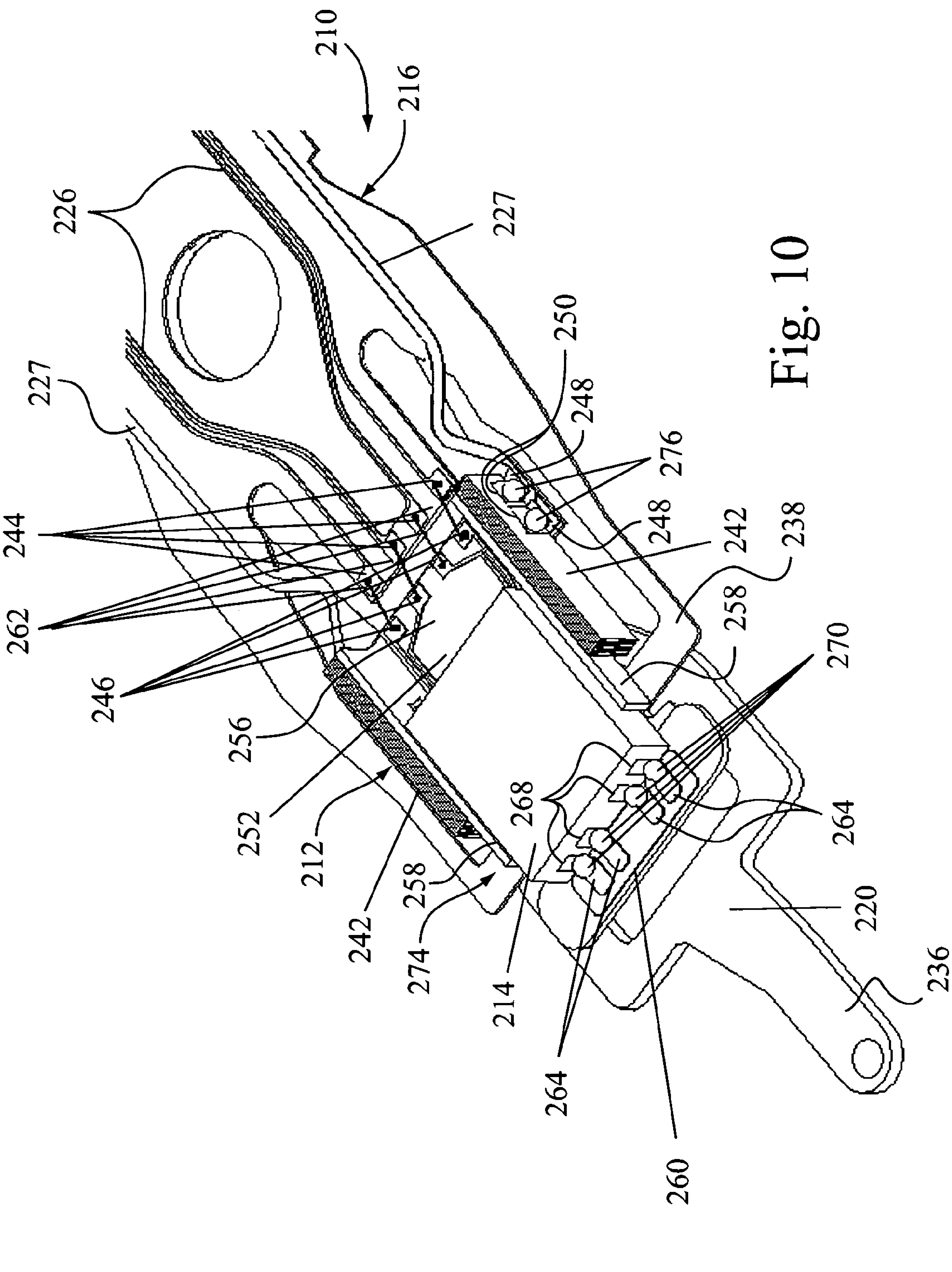

218
228
230
216
240
224
222
232
220
226
242
227
238
236
210
212
214
274
260

Fig. 9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216
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227
227
250
248
276
248
242
238
244
262
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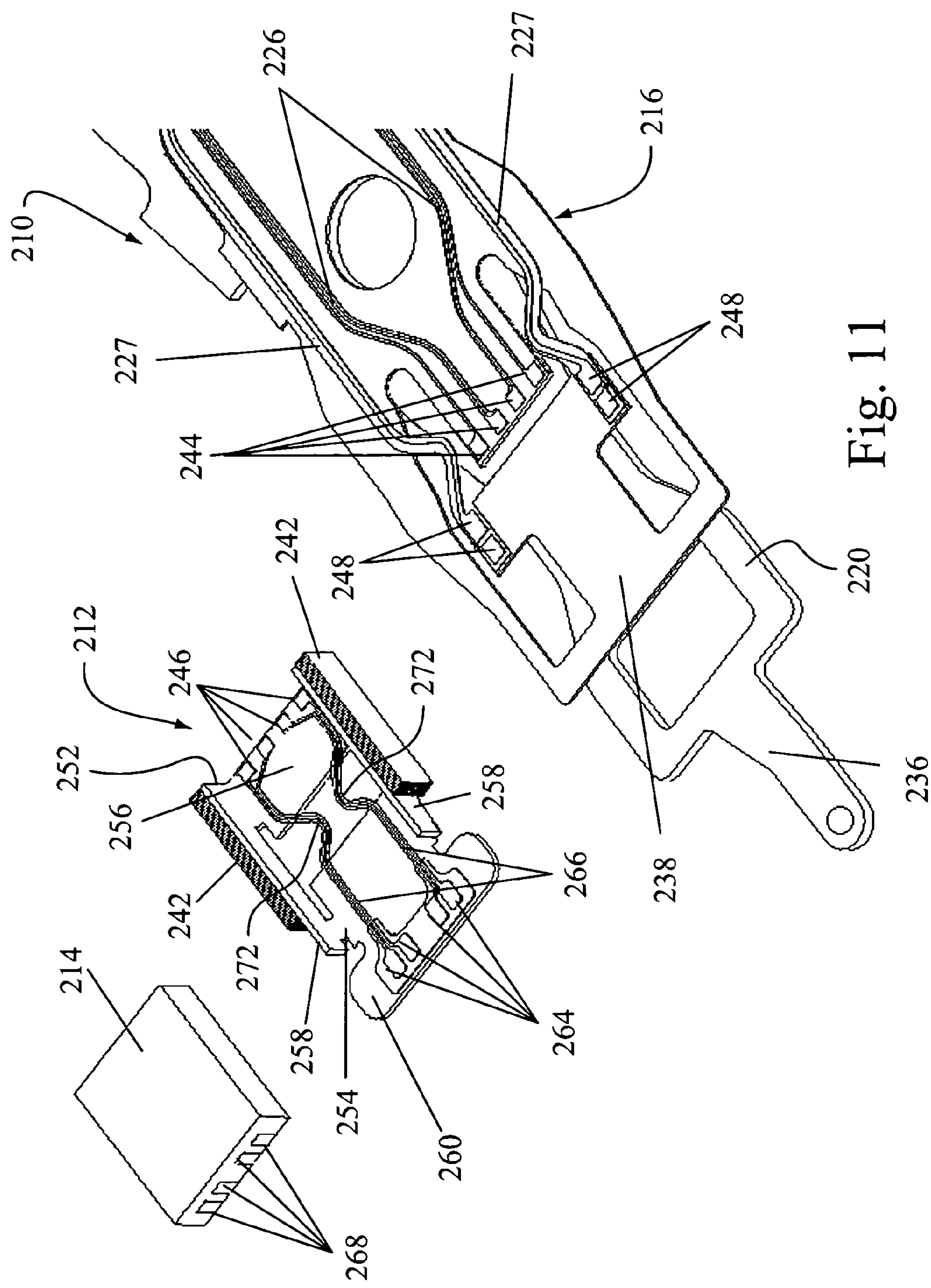
256
252
212
242
258
274
214
268
258
270
264
220
236
264
260

Fig. 10


210
212
214
216
220
226
227
227
236
238
242
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244
246
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252
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258
258
260
264
266
268
272
272

Fig. 11

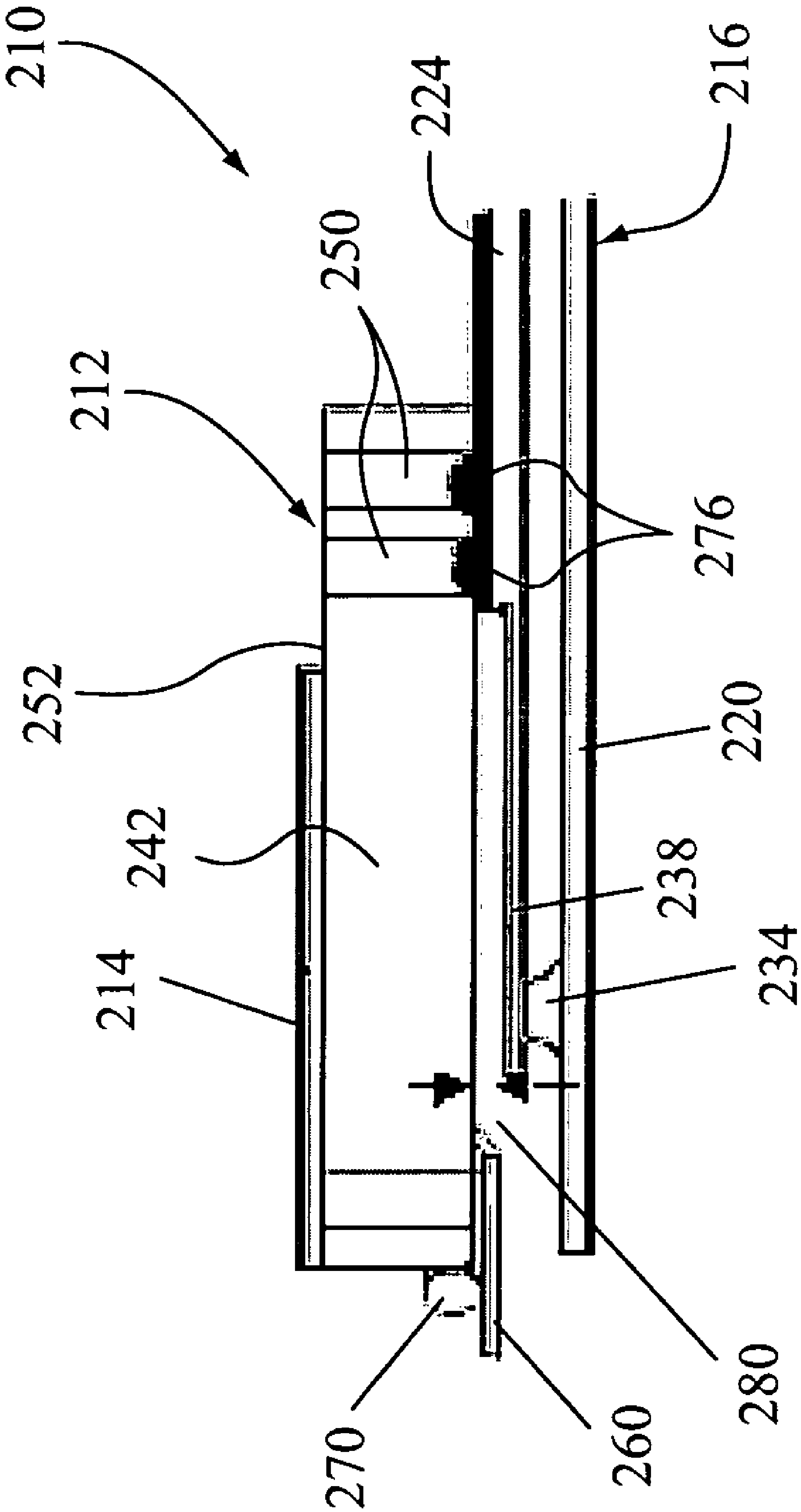

Fig. 12

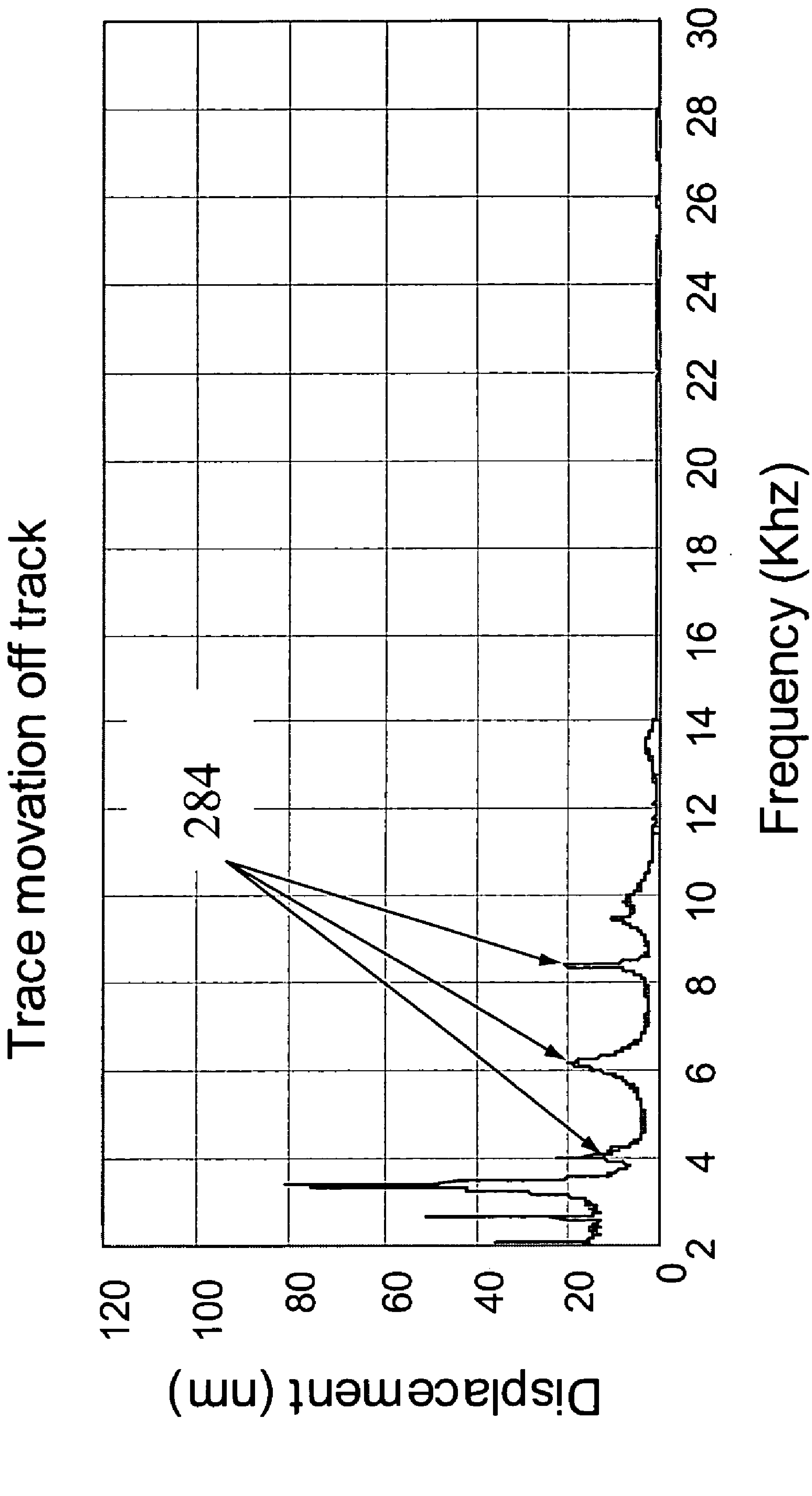
Trace movation off track
284
Displacement (nm)
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Frequency (Khz)

Fig. 13

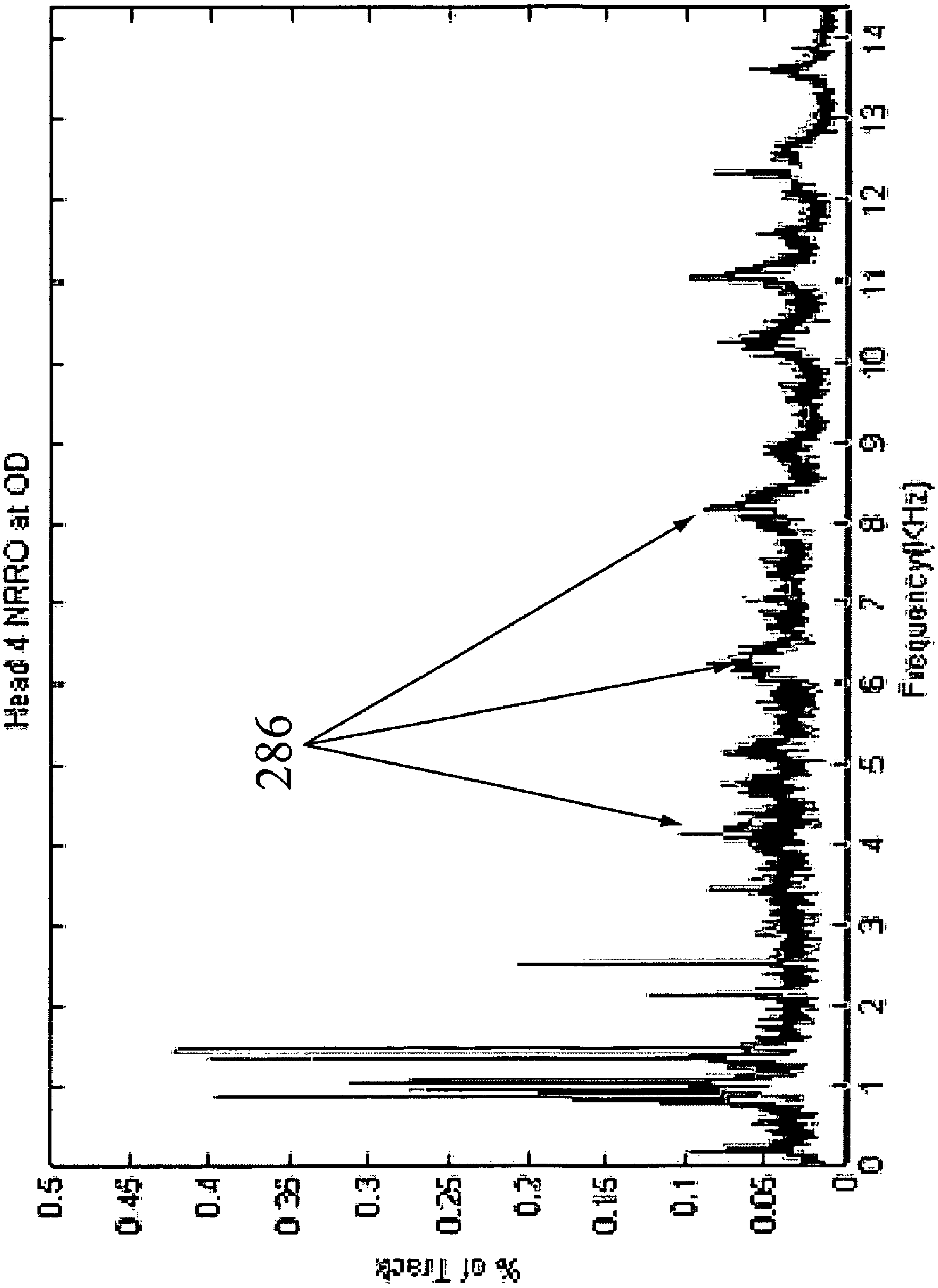
Head 4 NRRO at OD
% of Track
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Frequency(KHz)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
286

Fig. 14

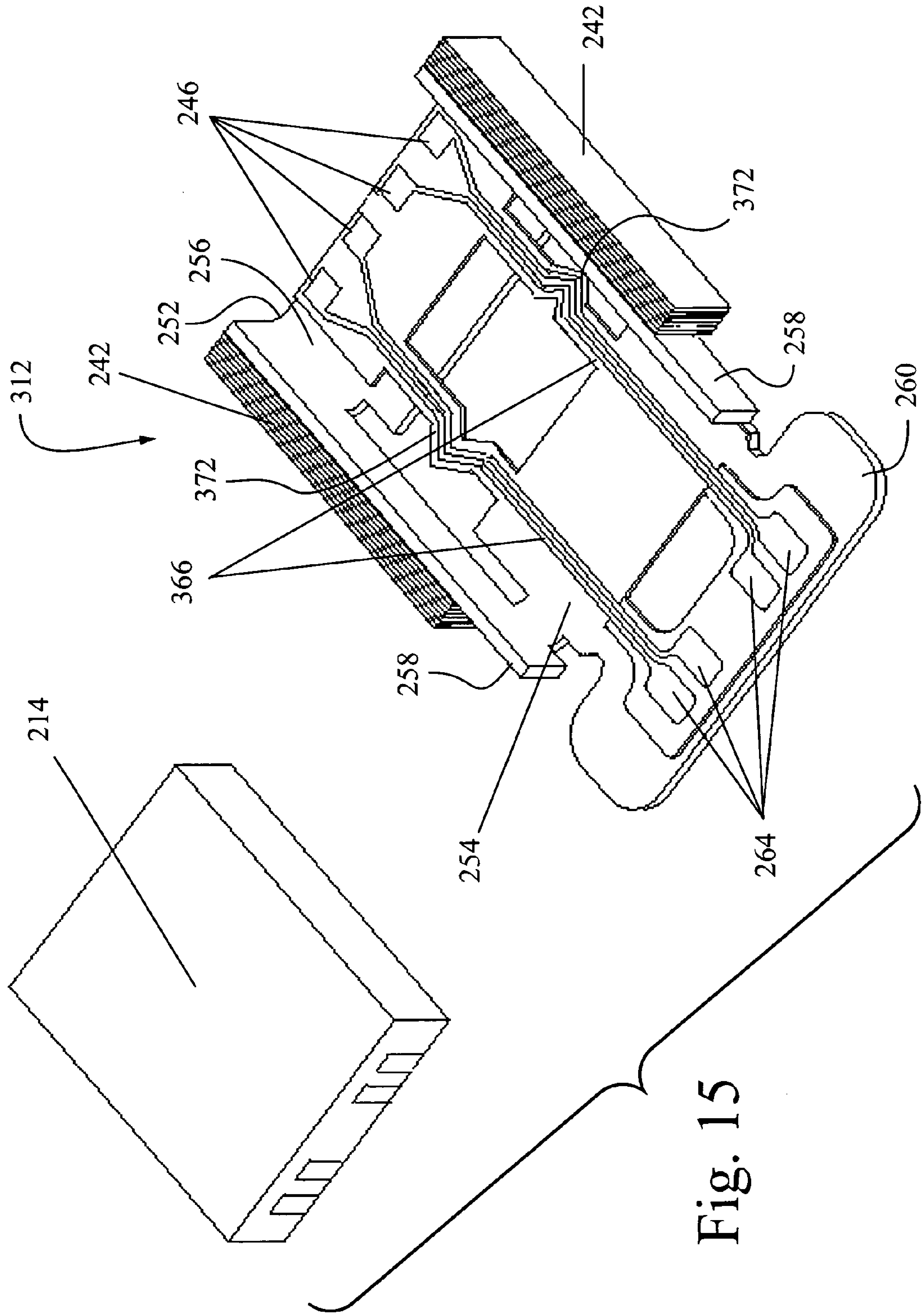

Fig. 15

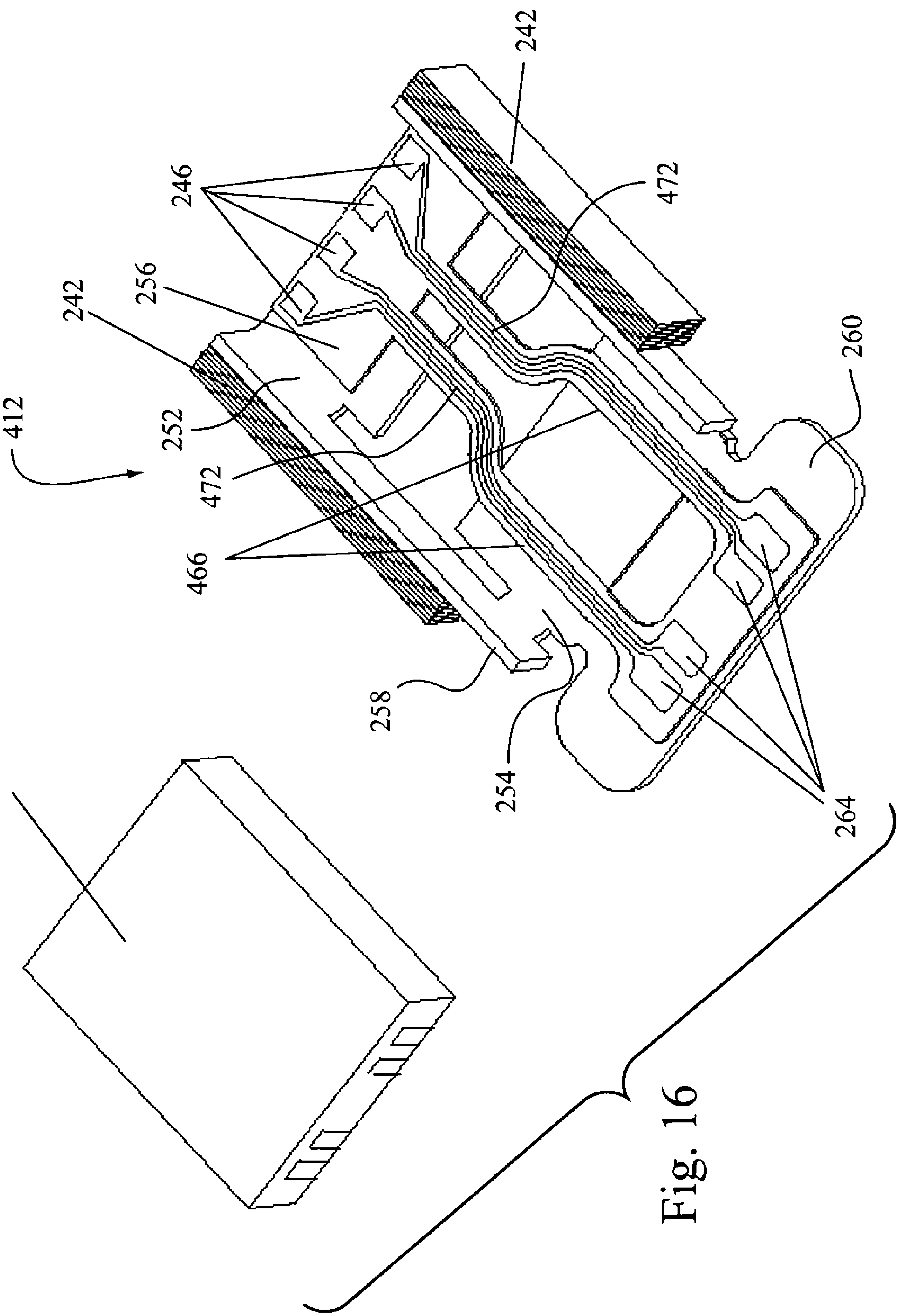

Fig. 16

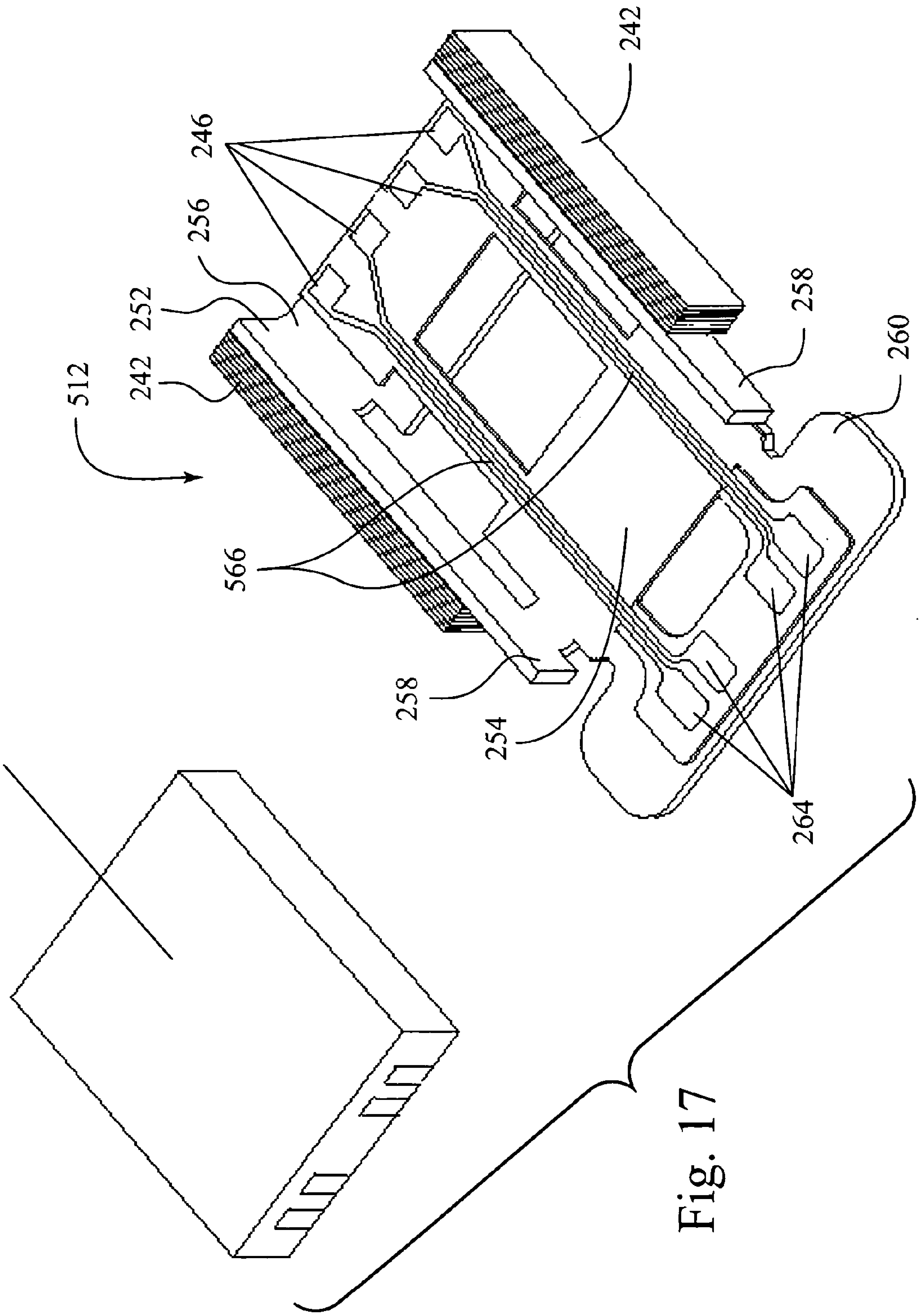

Fig. 17

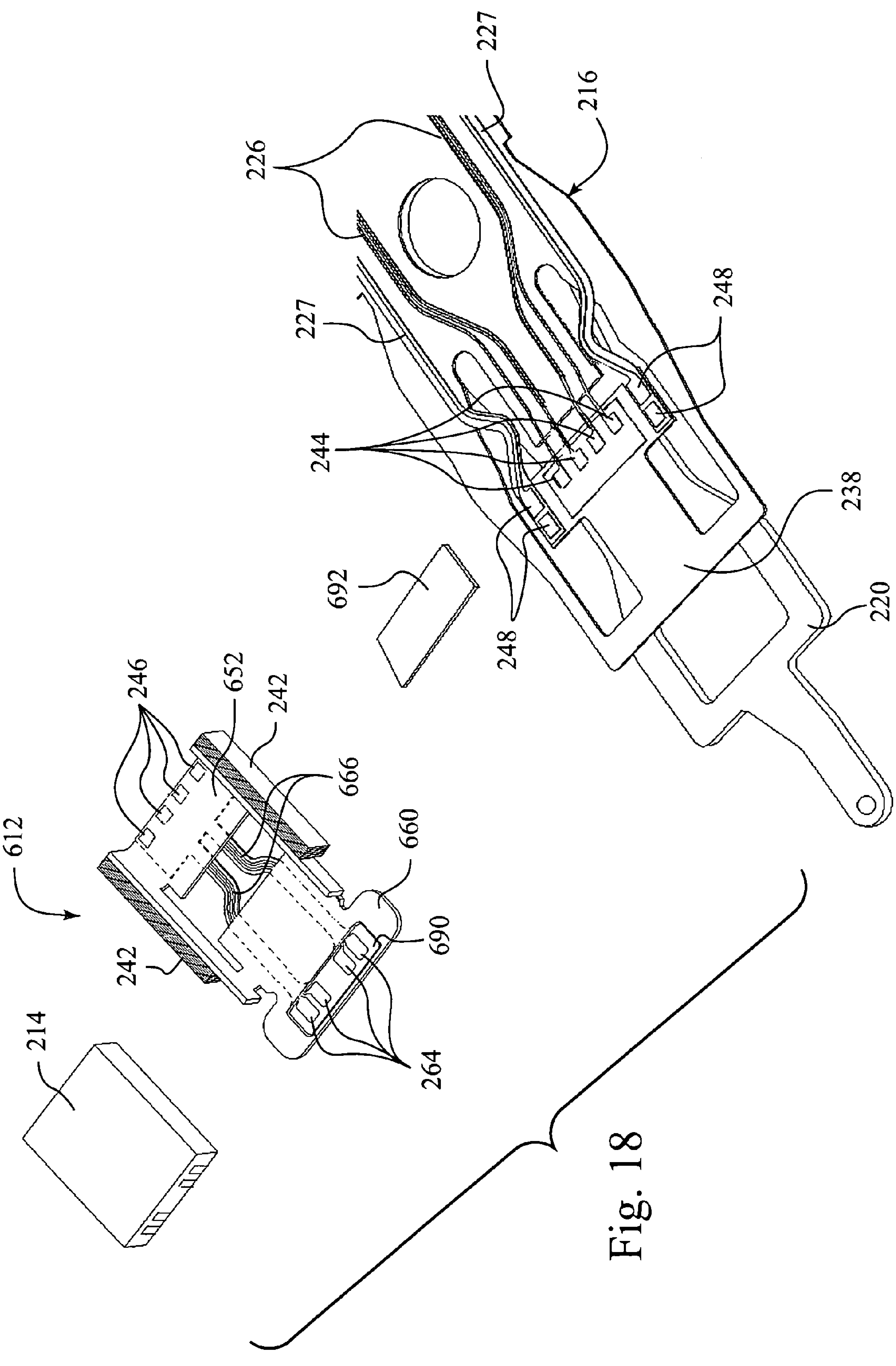
227
216
226
227
248
244
238
220
692
248
246
652
242
666
612
660
690
242
214
264

Fig. 18

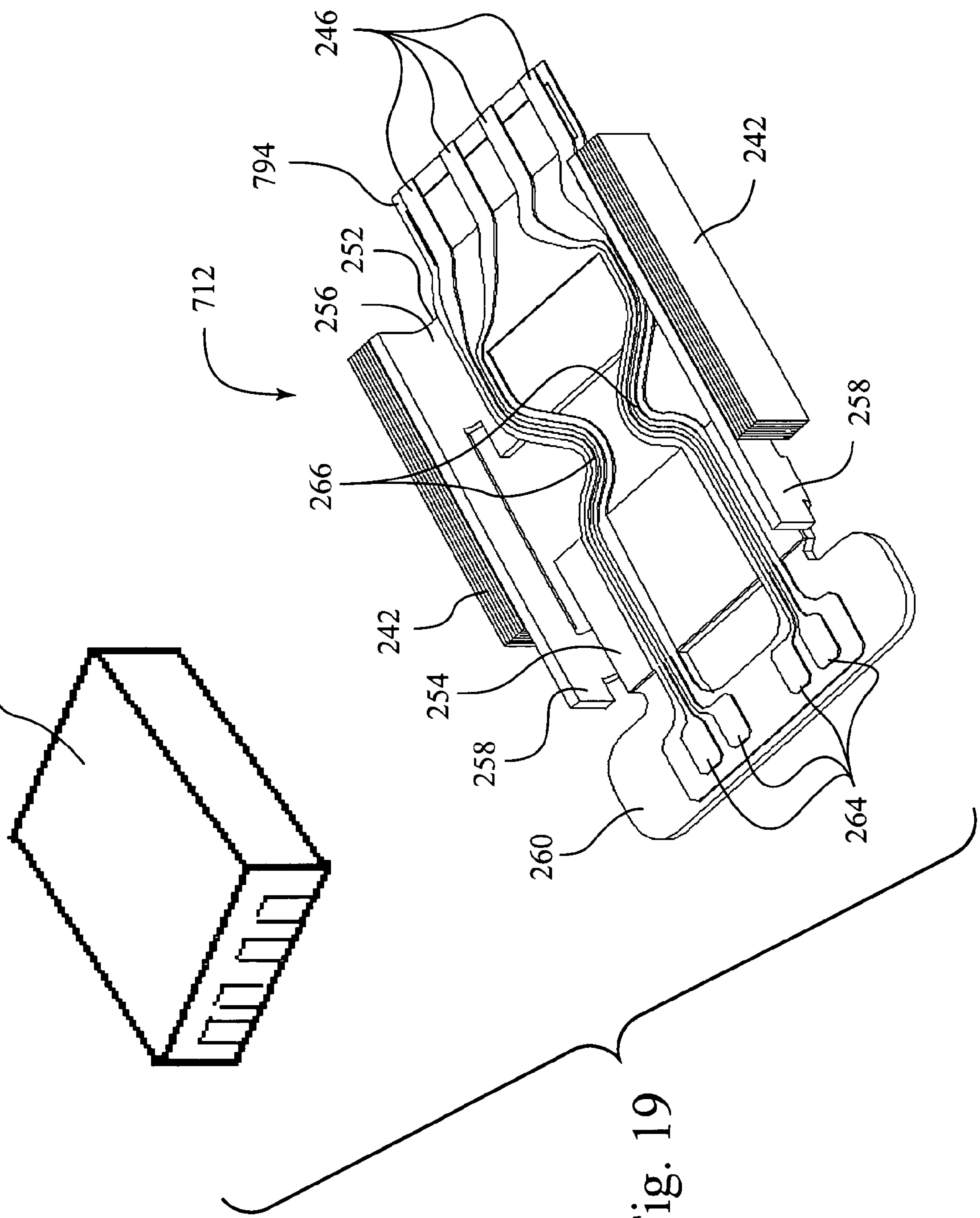

Fig. 19

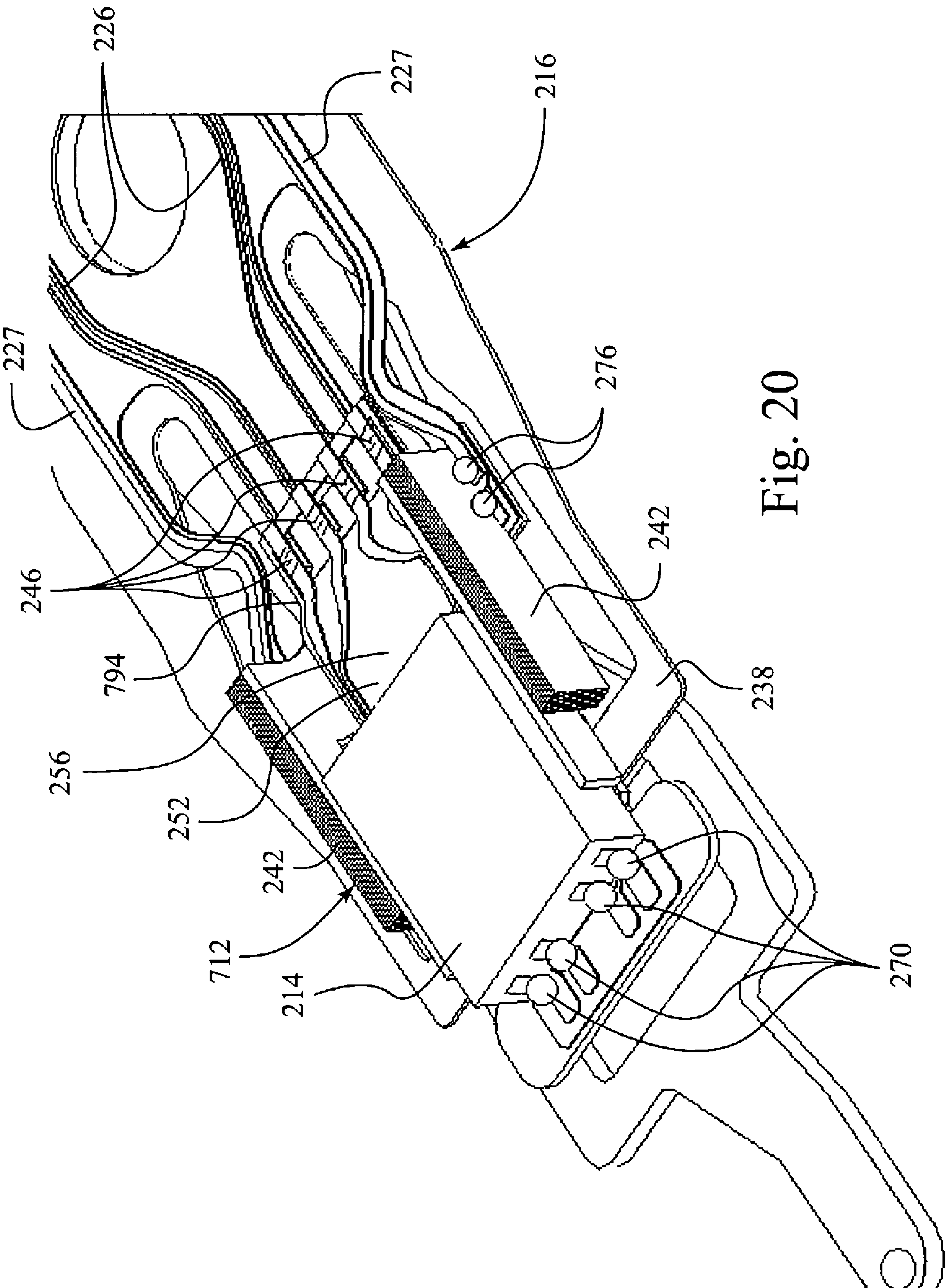

Fig. 20

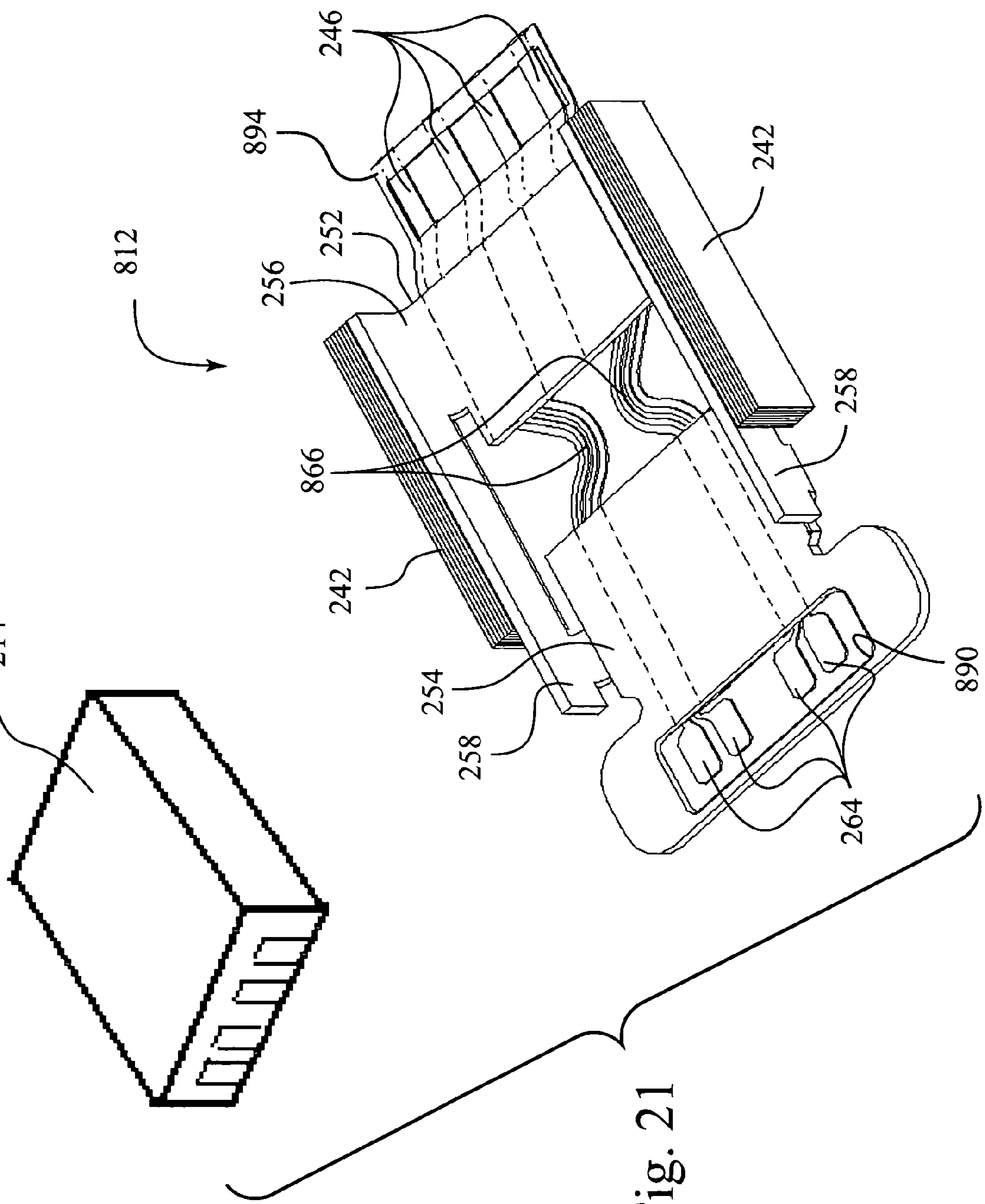

Fig. 21

MICRO-ACTUATOR WITH INTEGRATED TRACE AND BONDING PAD SUPPORT

FIELD OF THE INVENTION

The present invention relates to information recording disk drive devices and, more particularly, to a micro-actuator for a head gimbal assembly (HGA) of the disk drive device. More specifically, the present invention is directed to a micro-actuator that is structured to reduce trace vibrations.

BACKGROUND OF THE INVENTION

One known type of information storage device is a disk drive device that uses magnetic media to store data and a movable read/write head that is positioned over the media to selectively read from or write to the disk.

Consumers are constantly desiring greater storage capacity for such disk drive devices, as well as faster and more accurate reading and writing operations. Thus, disk drive manufacturers have continued to develop higher capacity disk drives by, for example, increasing the density of the information tracks on the disks by using a narrower track width and/or a narrower track pitch. However, each increase in track density requires that the disk drive device have a corresponding increase in the positional control of the read/write head in order to enable quick and accurate reading and writing operations using the higher density disks. As track density increases, it becomes more and more difficult using known technology to quickly and accurately position the read/write head over the desired information tracks on the storage media. Thus, disk drive manufacturers are constantly seeking ways to improve the positional control of the read/write head in order to take advantage of the continual increases in track density.

One approach that has been effectively used by disk drive manufacturers to improve the positional control of read/write heads for higher density disks is to employ a secondary actuator, known as a micro-actuator, that works in conjunction with a primary actuator to enable quick and accurate positional control for the read/write head. Disk drives that incorporate a micro-actuator are known as dual-stage actuator systems.

Various dual-stage actuator systems have been developed in the past for the purpose of increasing the access speed and fine tuning the position of the read/write head over the desired tracks on high density storage media. Such dual-stage actuator systems typically include a primary voice-coil motor (VCM) actuator and a secondary micro-actuator, such as a PZT element micro-actuator. The VCM actuator is controlled by a servo control system that rotates the actuator arm that supports the read/write head to position the read/write head over the desired information track on the storage media. The PZT element micro-actuator is used in conjunction with the VCM actuator for the purpose of increasing the positioning access speed and fine tuning the exact position of the read/write head over the desired track. Thus, the VCM actuator makes larger adjustments to the position of the read/write head, while the PZT element micro-actuator makes smaller adjustments that fine tune the position of the read/write head relative to the storage media. In conjunction, the VCM actuator and the PZT element micro-actuator enable information to be efficiently and accurately written to and read from high density storage media.

One known type of micro-actuator incorporates PZT elements for causing fine positional adjustments of the read/write head. Such PZT micro-actuators include associated electronics that are operable to excite the PZT elements on the micro-actuator to selectively cause expansion or contraction

thereof. The PZT micro-actuator is configured such that expansion or contraction of the PZT elements causes movement of the micro-actuator which, in turn, causes movement of the read/write head. This movement is used to make faster and finer adjustments to the position of the read/write head, as compared to a disk drive unit that uses only a VCM actuator. Exemplary PZT micro-actuators are disclosed in, for example, JP 2002-133803, entitled "Micro-actuator and HGA" and JP 2002-074871, entitled "Head Gimbal Assembly Equipped with Actuator for Fine Position, Disk Drive Equipped with Head Gimbals Assembly, and Manufacture Method for Head Gimbal Assembly."

FIG. **1** illustrates a conventional disk drive unit and show a magnetic disk **101** mounted on a spindle motor **102** for spinning the disk **101**. A voice coil motor arm **104** carries a head gimbal assembly (HGA) **100** that includes a micro-actuator **105** with a slider **103** incorporating a read/write head. A voice-coil motor (VCM) is provided for controlling the motion of the motor arm **104** and, in turn, controlling the slider **103** to move from track to track across the surface of the disk **101**, thereby enabling the read/write head to read data from or write data to the disk **101**. In operation, a lift force is generated by the aerodynamic interaction between the slider **103**, incorporating the read/write transducer, and the spinning magnetic disk **101**. The lift force is opposed by equal and opposite spring forces applied by a suspension of the HGA **100** such that a predetermined flying height above the surface of the spinning disk **101** is maintained over a full radial stroke of the motor arm **104**.

FIG. **2** illustrates the head gimbal assembly (HGA) **100** of the conventional disk drive device of FIG. **1** incorporating a dual-stage actuator. However, because of the inherent tolerances of the VCM and the head suspension assembly, the slider **103** cannot achieve quick and fine position control which adversely impacts the ability of the read/write head to accurately read data from and write data to the disk. As a result, a PZT micro-actuator **105**, as described above, is provided in order to improve the positional control of the slider and the read/write head. More particularly, the PZT micro-actuator **105** corrects the displacement of the slider **103** on a much smaller scale, as compared to the VCM, in order to compensate for the resonance tolerance of the VCM and/or head suspension assembly. The micro-actuator **105** enables, for example, the use of a smaller recording track pitch, and can increase the "tracks-per-inch" (TPI) value by 50% for the disk drive unit, as well as provide an advantageous reduction in the head seeking and settling time. Thus, the PZT micro-actuator **105** enables the disk drive device to have a significant increase in the surface recording density of the information storage disks used therein.

As shown in FIG. **2**, the HGA **100** includes a suspension **106** having a flexure **108**. The flexure **108** provides a suspension tongue **110** to load the PZT micro-actuator **105** and the slider **103**. Two outwardly protruding traces **112**, **114** are provided to the flexure **108** on opposite sides of the suspension tongue **110**. Each of the traces **112**, **114** has one end portion connected with a float plate **116** and another end portion connected with multi traces **118** that are electrically connected to bonding pads **120**.

Referring to FIG. **3**, a conventional PZT micro-actuator **105** includes a metal frame **130** which has a top support **132**, a bottom support **134**, and two side arms **136**, **138** that interconnect the two supports **132** and **134**. The side arms **136**, **138** each have a PZT element **140**, **142** attached thereto. The slider **103** is supported on the top support **132**.

Referring to FIG. **4**, the PZT micro-actuator **105** is physically coupled to the suspension tongue **110** by the bottom support **134** of the frame **130**. The bottom support **134** may be mounted on the suspension tongue **110** by epoxy or laser welding, for example. Three electrical connection balls **150** (gold ball bonding or solder ball bonding, GBB or SBB) are provided to couple the PZT micro-actuator **105** to the suspension traces **118** located at the side of each PZT element **140**, **142**. In addition, there are four metal balls **152** (GBB or SBB) for coupling the slider **103** to the traces **118** for electrical connection of the read/write transducers. When power is supplied through the suspension traces **118**, the PZT elements **140**, **142** expand or contract to cause the two side arms **136**, **138** to bend in a common lateral direction. The bending causes a shear deformation of the frame **130**, e.g., the rectangular shape of the frame becomes approximately a parallelogram, which causes movement of the top support **132**. This causes movement of the slider **103** connected thereto, thereby making the slider **103** move on the track of the disk in order to fine tune the position of the read/write head. In this manner, controlled displacement of slider **103** can be achieved for fine positional tuning.

FIG. **5** illustrates how the PZT micro-actuator **105** works when a voltage is applied to the PZT elements **140**, **142**. For example, when a positive sine voltage is input to the PZT element **140** of the micro-actuator which has a positive polarization, in the first half period, the PZT element **140** will shrink and cause the side arm **136** to deform as a water waveform shape. Since the slider **103** is mounted on the top support **132**, this deformation will cause the slider to move towards the left side. Likewise, when a negative sine voltage is input to the PZT element **142** of the micro-actuator which has a positive polarization, in the second half period, the PZT element **142** will shrink and cause the side arm **138** to deform as a water waveform shape. This deformation will cause the slider **103** to move towards the right side. Of course, this operation may depend on the electric control circle and PZT element polarization direction, but the work principle is well known.

Referring to FIG. **6**, two outwardly protruding traces **112**, **114** have to be used to electrically connect the multi-traces **118** with the float plate **116** which is electrically connected with the slider **103**. In order to reduce the trace resistance due to stiffness of the trace and maintain the micro-actuator function during operation, the traces **112**, **114** are shaped so as to curve and extend on opposite sides of the suspension tongue **110**. This arrangement allows the traces **112**, **114** to vibrate and move when the micro-actuator is operated during head seeking or settling operations in the disk drive device, which will cause the slider to be off-track. For a high RPM multi-plate disk drive device, the outwardly curved traces **112**, **114** will also cause a windage problem as air flow hits the traces or suspension. Both of these issues will cause slider PES (positional error signal) and NRRO (non-repeatable runout) performance to worsen, which will limit the capacity and performance of the disk drive device.

For example, FIG. **6** illustrates the motion of the traces **112**, **114** when the micro-actuator **105** is operated. As illustrated, when a voltage is input to the micro-actuator **105**, movement of the side arms **136**, **138** may cause the trace **112** to sway to the back side of the suspension **106** and the other trace **114** to sway to the top side of the slider **103**. This kind of motion will cause a suspension resonance motion, which is one of the sources that causes the slider to be off-track.

FIG. **7** illustrates trace motion displacement results for a prior art design when the micro-actuator is operated. As discussed above, the prior art design includes outwardly protruding traces **112**, **114**. The displacement of the traces is measured against the frequency. As illustrated, the displacement trend includes three peaks **160** (e.g., at 4 Khz, 6.3 kHz, and 8.5 Khz).

FIG. **8** illustrates related measurement data of the slider head NRRO performance for a prior art design. As illustrated, the peaks **170** show a slider head off track percentage with a different frequency. This shows a relatively large off track due to the trace motion.

Thus, there is a need for an improved system that does not suffer from the above-mentioned drawbacks.

SUMMARY OF THE INVENTION

One aspect of the present invention relates to a micro-actuator structured to reduce trace vibrations.

Another aspect of the invention relates to a micro-actuator having a frame with an integrated trace and bonding pad support.

Another aspect of the invention relates to a micro-actuator for a head gimbal assembly. The micro-actuator includes a frame, a first set of bonding pads provided to one end of the frame, a second set of bonding pads provided to an opposing end of the frame, and a trace integrated to the frame. The trace interconnects the first set of bonding pads and the second set of bonding pads.

Another aspect of the invention relates to a micro-actuator for a head gimbal assembly. The micro-actuator includes a bottom support adapted to be connected to a suspension of the head gimbal assembly, a top support adapted to support a slider of the head gimbal assembly, a pair of side arms that interconnect the bottom support and the top support, and a PZT element mounted to each of the side arms. Each PZT element is excitable to cause selective movement of the side arms which causes movement of the top support to cause movement of the slider. A bonding pad support is integrated to and extends from the top support. The bonding pad support includes slider bonding pads adapted to be electrically bonded with respective pads provided on the slider.

Yet another aspect of the invention relates to a head gimbal assembly including a micro-actuator, a slider, and a suspension that supports the micro-actuator and the slider. The micro-actuator includes a bottom support connected to the suspension by one of welding or epoxy bonding, a top support to support the slider, a pair of side arms that interconnect the bottom support and the top support, and a PZT element mounted to each of the side arms. Each PZT element is excitable to cause selective movement of the side arms which causes movement of the top support to cause movement of the slider. A bonding pad support is integrated to and extends from the top support. The bonding pad support includes slider bonding pads that are electrically bonded with respective pads provided on the slider.

Yet another aspect of the invention relates to a disk drive device. The disk drive device includes a head gimbal assembly including a micro-actuator, a slider, and a suspension that supports the micro-actuator and slider; a drive arm connected to the head gimbal assembly; a disk; and a spindle motor operable to spin the disk. The micro-actuator includes a bottom support connected to the suspension by one of welding or epoxy bonding, a top support to support the slider, a pair of side arms that interconnect the bottom support and the top support, and a PZT element mounted to each of the side arms. Each PZT element is excitable to cause selective movement of the side arms which causes movement of the top support to cause movement of the slider. A bonding pad support is integrated to and extends from the top support. The bonding pad support includes slider bonding pads that are electrically bonded with respective pads provided on the slider.

Still another aspect of the invention relates to a micro-actuator frame for a head gimbal assembly. The micro-actuator frame includes a bottom support adapted to be connected to a suspension of the head gimbal assembly, a top support adapted to support a slider of the head gimbal assembly, a pair of side arms that interconnect the bottom support and the top support, a first set of bonding pads provided to the bottom support and a second set of bonding pads provided to the top support, and a trace integrated to the frame and laminated between the side arms. The trace interconnects the first set of bonding pads and the second set of bonding pads.

Other aspects, features, and advantages of this invention will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, which are a part of this disclosure and which illustrate, by way of example, principles of this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings facilitate an understanding of the various embodiments of this invention. In such drawings:

FIG. **1** is a perspective view of a conventional disk drive unit;

FIG. **2** is a perspective view of a conventional head gimbal assembly (HGA);

FIG. **3** is a perspective view of a slider and PZT micro-actuator of the HGA shown in FIG. **2**;

FIG. **4** is a partial perspective view of the HGA shown in FIG. **2**;

FIG. **5** is a top view of the slider and PZT micro-actuator of the HGA shown in FIG. **2** in use;

FIG. **6** is a partial perspective view of the HGA shown in FIG. **2** in use;

FIG. **7** shows trace motion displacement results for a prior art design;

FIG. **8** shows slider head NRRO performance for a prior art design;

FIG. **9** is a perspective view of a head gimbal assembly (HGA) including a PZT micro-actuator according to an embodiment of the present invention;

FIG. **10** is a partial perspective of the HGA shown in FIG. **9**;

FIG. **11** is an exploded view of the HGA shown in FIG. **10**;

FIG. **12** is a side view of the HGA shown in FIG. **10**;

FIG. **13** shows trace motion displacement results for the HGA shown in FIG. **9**;

FIG. **14** shows slider head NRRO performance for the HGA shown in FIG. **9**;

FIG. **15** is a perspective view of a slider and a PZT micro-actuator according to another embodiment of the present invention;

FIG. **16** is a perspective view of a slider and a PZT micro-actuator according to another embodiment of the present invention;

FIG. **17** is a perspective view of a slider and a PZT micro-actuator according to another embodiment of the present invention;

FIG. **18** is an exploded view of a head gimbal assembly (HGA) including a PZT micro-actuator according to another embodiment of the present invention;

FIG. **19** is a perspective view of a slider and a PZT micro-actuator according to yet another embodiment of the present invention;

FIG. **20** is a perspective view of the slider and a PZT micro-actuator shown in FIG. **19** mounted to the suspension of a HGA; and

FIG. **21** is a perspective view of a slider and a PZT micro-actuator according to still another embodiment of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS

Various preferred embodiments of the instant invention will now be described with reference to the figures, wherein like reference numerals designate similar parts throughout the various views. As indicated above, the instant invention is designed to reduce trace vibrations in a head gimbal assembly (HGA) while precisely actuating the slider using the micro-actuator. An aspect of the instant invention is to provide a micro-actuator that includes an integrated trace and bonding pad support configured to reduce trace vibrations in the HGA. By reducing the trace vibrations in the HGA, the performance characteristics of the device are improved.

Several example embodiments of a micro-actuator for a HGA will now be described. It is noted that the micro-actuator may be implemented in any suitable disk drive device having a micro-actuator in which it is desired to reduce trace vibrations, regardless of the specific structure of the HGA as illustrated in the figures. That is, the invention may be used in any suitable device having a micro-actuator in any industry.

FIGS. **9-12** illustrates a head gimbal assembly (HGA) **210** incorporating a PZT micro-actuator **212** according to a first exemplary embodiment of the present invention. The HGA **210** includes a PZT micro-actuator **212**, a slider **214**, and a suspension **216** to load or suspend the PZT micro-actuator **212** and the slider **214**.

As illustrated, the suspension **216** includes a base plate **218**, a load beam **220**, a hinge **222**, a flexure **224**, and inner and outer suspension traces **226**, **227** in the flexure **224**. The base plate **218** includes a mounting hole **228** for use in connecting the suspension **216** to a drive arm of a voice coil motor (VCM) of a disk drive device. The shape of the base plate **218** may vary depending on the configuration or model of the disk drive device. Also, the base plate **218** is constructed of a relatively hard or rigid material, e.g., metal, to stably support the suspension **216** on the drive arm of the VCM.

The hinge **222** is mounted onto the base plate **218** and load beam **220**, e.g., by welding. As illustrated, the hinge **222** includes a hole **230** that align with the hole **228** provided in the base plate **218**. Also, the hinge **222** includes a holder bar **232** for supporting the load beam **220**.

The load beam **220** is mounted onto the holder bar **232** of the hinge **222**, e.g., by welding. The load beam **220** has a dimple **234** formed thereon for engaging the flexure **224** (see FIG. **12**). The load beam **220** functions as a spring or shock absorber to buffer the suspension **216** from the slider **214**. An optional lift tab **236** may be provided on the load beam **220** to lift the HGA **210** from the disk when the disk is not rotated.

The flexure **224** is mounted to the hinge **222** and the load beam **220**, e.g., by lamination or welding. The flexure **224** provides a suspension tongue **238** to couple the PZT micro-actuator **212** to the suspension **216** (see FIG. **11**). The suspension tongue **238** engages the dimple **234** on the load beam **220**. Also, the suspension traces **226**, **227** are provided on the flexure **224** to electrically connect a plurality of connection pads **240** (which connect to an external control system) with the slider **214** and the PZT elements **242** on the PZT micro-actuator **212**. The suspension traces **226**, **227** may be a flexible printed circuit (FPC) and may include any suitable number of lines.

As best shown in FIGS. **10** and **11**, bonding pads **244** are directly connected to the inner suspension traces **226** to electrically connect the inner suspension traces **226** with bonding pads **246** provided on the frame of the PZT micro-actuator **212**, which is electrically connected to the slider **214**. Also, bonding pads **248** are directly connected to the outer suspension traces **227** to electrically connect the outer suspension traces **227** with bonding pads **250** provided on the PZT elements **242**.

A voice-coil motor (VCM) is provided in the disk drive device for controllably driving the drive arm and, in turn, the HGA **210** in order to enable the HGA **210** to position the slider **214**, and associated read/write head, over any desired information track on a disk in the disk drive device. The PZT micro-actuator **212** is provided to enable faster and finer positional control for the device, as well as to reduce the head seeking and settling time during operation. Thus, when the HGA **210** is incorporated into a disk drive device, a dual-stage actuator system is provided in which the VCM actuator provides large positional adjustments and the PZT micro-actuator **212** provides fine positional adjustments for the read/write head.

FIG. **11** illustrates the PZT micro-actuator **212** and slider **214** removed from the suspension **216**. As illustrated, the PZT micro-actuator **212** includes a micro-actuator frame **252** and PZT elements **242** mounted to the micro-actuator frame **252**. The micro-actuator frame **252** includes a top support **254**, a bottom support **256**, side arms **258** that interconnect the top support **254** and bottom support **256**, and a bonding pad support **260** that extends from the top support **254**. The micro-actuator frame **252** may be constructed of any suitable material, e.g., metal, and may be constructed using any suitable process.

As best shown in FIG. **10**, the bottom support **256** is structured to connect the micro-actuator frame **252** to the suspension **216**. Specifically, the bottom support **256** is partially mounted to the suspension tongue **238** of the flexure **224**, e.g., by epoxy, resin, or welding by laser. Also, suspension bonding pads **246**, e.g., four bonding pads, are provided on the bottom support **256**. The suspension bonding pads **246** are electrically coupled by electric connections **262** with respective bonding pads **244** provided on the suspension **216**, e.g., by wire bonding. This connects the bottom support **256** to the suspension **216** and electrically connects the micro-actuator frame **252** with the inner suspension traces **226**. Also, a parallel gap **280** is provided between the suspension tongue **238** and the PZT micro-actuator **212** to allow the PZT micro-actuator **212** to move freely in use, as shown in FIG. **12**.

The top support **254** is structured to connect the micro-actuator frame **252** to the slider **214**. Specifically, slider bonding pads **264**, e.g., four bonding pads, are provided on the bonding pad support **260** extending from the top support **254**. As shown in FIG. **11**, the slider bonding pads **264** are electrically connected to the suspension bonding pads **246** through traces **266** integrated into the frame **252**. The slider **214** has bonding pads **268**, e.g., four bonding pads, on an end thereof corresponding to the slider bonding pads **264** of the bonding pad support **260**. The top support **254** supports the slider **214** thereon and the slider bonding pads **264** of the bonding pad support **260** are electrically bonded with respective pads **268** provided on the slider **214** using, for example, electric connection balls (GBB or SBB) **270** (see FIGS. **10** and **12**). This connects the top support **254** to the slider **214** and electrically connects the slider **214** and its read/write elements to the inner suspension traces **226** on the suspension **216**.

In the illustrated embodiment, the trace **266** includes four lines between the four slider bonding pads **264** and the four suspension bonding pads **246**. However, any suitable number of pads and trace lines may be used. Also, as best shown in FIG. **11**, intermediate portions **272** of opposing trace lines curve inwardly towards one another. However, the trace lines may have any suitable configuration.

The side arms **258** interconnect the top support **254** and the bottom support **256**. A PZT element **242** is mounted to each of the side arms **258** of the nicro-actuator frame **252** to provide the PZT micro-actuator **112**. Each PZT element **242** has a plate-like shape and may be formed by laminated thin films consisting of piezoelectric material such as PZT and Ni—Ag or Pt or gold metal as electrode. In another embodiment, the PZT element **242** may be a ceramic PZT with a single layer or a multi-layer. However, one or more PZT elements **242** may be mounted to the side arms **258** in any suitable manner.

A slider **214** is mounted to the PZT micro-actuator **212** to provide a slider and PZT micro-actuator assembly **274**. The slider **214** is mounted to the PZT micro-actuator **212** as shown in FIG. **10**. As explained above, the slider **214**, incorporating the read/write head, is electrically bonded to the slider bonding pads **264** of the micro-actuator frame **252** by electrical connection balls (GBB or SBB) **270**.

The slider and PZT micro-actuator assembly **274** is electrically connected to the suspension **216** of the HGA **210**. As explained above, electrical connections **262** are provided to electrically connect the suspension bonding pads **246** on the bottom support **256** of the micro-actuator frame **252** to the bonding pads **244** bonded to the inner suspension traces **226** provided on the suspension **216**. In addition, the PZT elements **242** provided on the PZT micro-actuator **212** are electrically connected to the outer suspension traces **227**. Specifically, the bonding pads **250**, e.g., two bonding pads, provided on the PZT elements **242** are electrically connected to the bonding pads **248**, e.g., two bonding pads, on the outer suspension traces **227** using electrical connection balls (GBB or SBB) **276**. This allows power to be applied via the outer suspension traces **227** to the PZT elements **242**.

In use, the PZT elements **242** are excited, e.g., by applying voltage thereto, to selectively cause expansion or contraction thereof. The PZT micro-actuator **212** is configured such that expansion or contraction of the PZT elements **242** causes movement of the side arms **258**, which causes movement of the top support **254**, which, in turn, causes movement of the slider **214** coupled thereto.

Because the trace **266** and the bonding pad support **260** are integrated into the micro-actuator frame **252**, these components are not subject to excessive vibration when the PZT micro-actuator **212** is operated. By reducing the trace vibrations in the HGA, the performance characteristics of the disk drive device are improved. Moreover, PZT micro-actuator **212** with integrated trace **266** and bonding pad support **260** improves the process yield as these components are not easily deformed during the manufacture of the suspension, HGA, and disk drive device.

FIG. **13** illustrates trace motion displacement results when the PZT micro-actuator **212** is operated. When compared to the results of the prior art design in FIG. **7**, the three peaks **284** of FIG. **13** are improved with respect to the three peaks **160** of FIG. **7** (e.g., at 4 Khz, 6.3 kHz, and 8.5 Khz).

FIG. **14** illustrates testing data of slider head NRRO performance for the PZT micro-actuator **212**. When compared to the results of the prior art design in FIG. **8**, the peaks **286** of FIG. **14** are improved with respect to the peaks **170** of FIG. **8**.

As noted above, the trace lines interconnecting the slider bonding pads **264** and the suspension bonding pads **246** may have any suitable configuration. For example, FIG. **15** illustrates a PZT micro-actuator **312** according to another exemplary embodiment of the present invention. In this embodiment, intermediate portions **372** of opposing trace lines of the traces **366** curve outwardly away from one another. The remaining components of the PZT micro-actuator **312** are substantially similar to the PZT micro-actuator **212** and indicated with similar reference numerals.

FIG. **16** illustrates a PZT micro-actuator **412** according to another exemplary embodiment of the present invention. In this embodiment, end portions **472** of opposing trace lines of the traces **466** curve inwardly towards one another. The remaining components of the PZT micro-actuator **412** are substantially similar to the PZT micro-actuator **212** and indicated with similar reference numerals.

FIG. **17** illustrates a PZT micro-actuator **512** according to another exemplary embodiment of the present invention. In this embodiment, opposing trace lines of the traces **566** are substantially parallel with one another. The remaining components of the PZT micro-actuator **512** are substantially similar to the PZT micro-actuator **212** and indicated with similar reference numerals.

FIG. **18** illustrates a PZT micro-actuator **612** according to another exemplary embodiment of the present invention. In this embodiment, the traces **666** are provided on the back side of the frame **652**. The traces **666** may have any suitable configuration as described above. As illustrated, an opening or window **690** is provided in the bonding pad support **660** in order to expose the slider bonding pads **264** for bonding with the slider **214**. Also, ACF 692 or other suitable material may be used to physically and electrically couple the suspension bonding pads **246** to the pads **244** provided on the suspension **216**. The remaining components of the PZT micro-actuator **612** are substantially similar to the PZT micro-actuator **212** and indicated with similar reference numerals.

FIGS. **19** and **20** illustrates a PZT micro-actuator **712** according to yet another exemplary embodiment of the present invention. In this embodiment, the bottom support **256** of the frame **252** may include an extension **794**, e.g., long tail leader, to facilitate connection with the suspension **216**. For example, the bottom support **256** may be physically mounted to the suspension tongue **238** of the suspension **216**, e.g., by laser welding or epoxy. The extension **794**, including the suspension bonding pads **246**, may be electrically coupled to the pads **244** provided on the suspension **216**, e.g., by US bonding. The remaining components of the PZT micro-actuator **712** are substantially similar to the PZT micro-actuator **212** and indicated with similar reference numerals.

FIG. **21** illustrate a PZT micro-actuator **812** according to still another exemplary embodiment of the present invention. In this embodiment, the bottom support **256** of the frame **252** may include an extension **894**, e.g., long tail leader, to facilitate connection with the suspension **216** as described above. Further, the traces **866** interconnecting the slider bonding pads **264** and the suspension bonding pads **246** are provided on the back side of the frame **852**. The traces **866** may have any suitable configuration as described above. As illustrated, an opening **890** is provided in the bonding pad support **860** in order to expose the slider bonding pads **264** for bonding with the slider **214**. The remaining components of the PZT micro-actuator **812** are substantially similar to the PZT micro-actuator **212** and indicated with similar reference numerals.

A head gimbal assembly **210** incorporating a PZT micro-actuator **212**, **312**, **412**, **512**, **612**, **712**, **812** according to embodiments of the present invention may be provided to a disk drive device (HDD). The HDD may be of the type described above in connection with FIG. **1**. Because the structure, operation and assembly processes of disk drive devices are well known to persons of ordinary skill in the art, further details regarding the disk drive device are not provided herein so as not to obscure the invention. The PZT micro-actuator can be implemented in any suitable disk drive device having a micro-actuator or any other device with a micro-actuator. In an embodiment, the PZT micro-actuator is used in a high RPM disk drive device.

While the invention has been described in connection with what are presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the invention.

What is claimed is:

1. A micro-actuator for a head gimbal assembly, comprising:

a frame;

a first set of bonding pads provided to one end of the frame and a second set of bonding pads provided to an opposing end of the frame; and

a trace integrated to the frame, the trace interconnecting the first set of bonding pads and the second set of bonding pads,

wherein the trace is substantially planar with respect to a single surface of the frame.

2. The micro-actuator according to claim **1**, wherein the frame includes a bonding pad support integrated to the frame, the bonding pad support supporting one of the first set of bonding pads and the second set of bonding pads.

3. The micro-actuator according to claim **1**, wherein the frame includes a bonding pad support integrated to the frame, the bonding pad support having at least one opening that supports and exposes one of the first set of bonding pads and the second set of bonding pads.

4. A micro-actuator for a head gimbal assembly, comprising:

a bottom support adapted to be connected to a suspension of the head gimbal assembly, the bottom support including suspension bonding pads adapted to be electrically bonded with respective pads provided on the suspension;

a top support adapted to support a slider of the head gimbal assembly;

a pair of side arms that interconnect the bottom support and the top support;

a PZT element mounted to each of the side arms, each PZT element being excitable to cause selective movement of the side arms which causes movement of the top support to cause movement of the slider; and

a bonding pad support integrated to and extending from the top support, the bonding pad support including slider bonding pads adapted to be electrically bonded with respective pads provided on the slider,

wherein the suspension bonding pads are electrically connected to the slider bonding pads through a trace that is integrated to the bottom support, the top support and the bonding pad support and supported only by the bottom support, the top support and the bonding pad support.

5. The micro-actuator according to claim **4**, wherein the trace includes opposing trace lines having intermediate portions that curve inwardly towards one another.

6. The micro-actuator according to claim 4, wherein the trace includes opposing trace lines having intermediate portions that curve outwardly away from one another.

7. The micro-actuator according to claim 4, wherein the trace includes opposing trace lines having end portions that curve inwardly towards one another.

8. The micro-actuator according to claim 4, wherein the trace includes opposing trace lines that are substantially parallel with one another.

9. The micro-actuator according to claim 4, wherein the trace is integrated into a front surface of the bottom support, the top support, and the bonding pad support that faces towards the slider.

10. The micro-actuator according to claim 4, wherein the trace is integrated into a back surface of the bottom support, the top support, and the bonding pad support that faces away from the slider.

11. The micro-actuator according to claim 10, wherein the bonding pad support includes an opening that exposes the slider bonding pads so that the slider bonding pads can be electrically bonded with respective pads provided on the slider.

12. The micro-actuator according to claim 4, further comprising an extension integrated to and extending from the bottom support, the extension including suspension bonding pads adapted to be electrically bonded with respective pads provided on the suspension.

13. The micro-actuator according to claim 12, wherein the suspension bonding pads are electrically connected to the slider bonding pads through a trace that is integrated into the bottom support, the top support, the bonding pad support, and the extension.

14. The micro-actuator according to claim 13, wherein the trace includes opposing trace lines having intermediate portions that curve inwardly towards one another.

15. The micro-actuator according to claim 13, wherein the trace is integrated into a front surface of the bottom support, the top support, the bonding pad support, and the extension that faces towards the slider.

16. The micro-actuator according to claim 13, wherein the trace is integrated into a back surface of the bottom support, the top support, the bonding pad support, and the extension that faces away from the slider.

17. The micro-actuator according to claim 16, wherein the bonding pad support includes an opening that exposes the slider bonding pads so that the slider bonding pads can be electrically bonded with respective pads provided on the slider.

18. A head gimbal assembly comprising:

a micro-actuator;

a slider; and

a suspension that supports the micro-actuator and the slider,

wherein the micro-actuator includes:

a bottom support connected to the suspension by one of welding or epoxy bonding, the bottom support including suspension bonding pads adapted to be electrically bonded with respective pads provided on the suspension;

a top support to support the slider;

a pair of side arms that interconnect the bottom support and the top support;

a PZT element mounted to each of the side arms, each PZT element being excitable to cause selective movement of the side arms which causes movement of the top support to cause movement of the slider; and

a bonding pad support integrated to and extending from the top support, the bonding pad support including slider bonding pads that are electrically bonded with respective pads provided on the slider,

wherein the suspension bonding pads are electrically connected to the slider bonding pads through a trace that is integrated to the bottom support, the top support and the bonding pad support and supported only by the bottom support, the top support and the bonding pad support.

19. The head gimbal assembly according to claim 18, wherein the slider includes a read/write element for magnetic recording.

20. The head gimbal assembly according to claim 18, wherein the bottom support is connected to a suspension tongue of the suspension.

21. The head gimbal assembly according to claim 18, wherein the trace includes opposing trace lines having intermediate portions that curve inwardly towards one another.

22. The head gimbal assembly according to claim 18, wherein the trace includes opposing trace lines having intermediate portions that curve outwardly away from one another.

23. The head gimbal assembly according to claim 18, wherein the trace includes opposing trace lines having end portions that curve inwardly towards one another.

24. The head gimbal assembly according to claim 18, wherein the trace includes opposing trace lines that are substantially parallel with one another.

25. The head gimbal assembly according to claim 18, wherein the trace is integrated into a front surface of the bottom support, the top support, and the bonding pad support that faces towards the slider.

26. The head gimbal assembly according to claim 18, wherein the trace is integrated into a back surface of the bottom support, the top support, and the bonding pad support that faces away from the slider.

27. The head gimbal assembly according to claim 26, wherein the bonding pad support includes an opening that exposes the slider bonding pads so that the slider bonding pads can be electrically bonded with respective pads provided on the slider.

28. The head gimbal assembly according to claim 18, further comprising an extension integrated to and extending from the bottom support, the extension including suspension bonding pads adapted to be electrically bonded with respective pads provided on the suspension.

29. The head gimbal assembly according to claim 28, wherein the suspension bonding pads are electrically connected to the slider bonding pads through a trace that is integrated into the bottom support, the top support, the bonding pad support, and the extension.

30. The head gimbal assembly according to claim 29, wherein the trace includes opposing trace lines having intermediate portions that curve inwardly towards one another.

31. The head gimbal assembly according to claim 29, wherein the trace is integrated into a front surface of the bottom support, the top support, the bonding pad support, and the extension that faces towards the slider.

32. The head gimbal assembly according to claim 29, wherein the trace is integrated into a back surface of the bottom support, the top support, the bonding pad support, and the extension that faces away from the slider.

33. The head gimbal assembly according to claim 32, wherein the bonding pad support includes an opening that exposes the slider bonding pads so that the slider bonding pads can be electrically bonded with respective pads provided on the slider.

34. A disk drive device comprising:

a head gimbal assembly including a micro-actuator, a slider, and a suspension that supports the micro-actuator and slider;

a drive arm connected to the head gimbal assembly;

a disk; and

a spindle motor operable to spin the disk,

wherein the micro-actuator includes:

a bottom support connected to the suspension by one of welding or epoxy bonding, the bottom support including suspension bonding pads adapted to be electrically bonded with respective pads provided on the suspension;

a top support to support the slider;

a pair of side arms that interconnect the bottom support and the top support;

a PZT element mounted to each of the side arms, each PZT element being excitable to cause selective movement of the side arms which causes movement of the top support to cause movement of the slider; and

a bonding pad support integrated to and extending from the top support, the bonding pad support including slider bonding pads that are electrically bonded with respective pads provided on the slider,

wherein the suspension bonding pads are electrically connected to the slider bonding pads through a trace that is integrated to the bottom support, the top support and the bonding pad support and supported only by the bottom support, the top support and the bonding pad support.

35. A micro-actuator frame for a head gimbal assembly, comprising:

a bottom support adapted to be connected to a suspension of the head gimbal assembly;

a top support adapted to support a slider of the head gimbal assembly;

a pair of side arms that interconnect the bottom support and the top support;

a first set of bonding pads provided to the bottom support and a second set of bonding pads provided to the top support; and

a trace integrated to the bottom support and the top support, supported only by the bottom support and the top support, and laminated between the side arms, the trace interconnecting the first set of bonding pads and the second set of bonding pads.

36. The micro-actuator frame according to claim **35**, further comprising a bonding pad support integrated to and extending from the top support, the bonding pad support supporting the second set of bonding pads.

37. The micro-actuator frame according to claim **35**, wherein the trace includes opposing trace lines having end portions that curve inwardly towards one another, the end portions that curve inwardly towards one another being laminated on the bottom support.

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